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OUR INLAND WATERWAYS

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WE are in the throes of our second waterway agitation. The movement extends from the Atlantic to the Pacific and from the Great Lakes to the Gulf, and involves every state and territory. The first agitation followed hard on the Revolution, and in far-reaching effect shared with the Declaration of Independence the distinction of opening the most important era in American history; the present agitation seems to promise a peaceful yet potent revolution in our material progress and in appreciation of the fundamental elements of national character and strength.

The Early Agitation and its Results

When the American colonies revolted against a tax imposed by a foreign monarchy the pendulum of feeling swung far toward purely local self-government throughout independent states. Yet within five years after the states were established and loosely confederated, questions of interstate relations arose; and when George Washington and others foresaw the increasing importance of commerce, and sought to develop the requisite facilities in connection with the typical interstate Potomac River, they induced Virginia and Maryland jointly to create a commission to devise plans of procedure. This was our original Inland Waterways Commission, the prototype, too, of the Interstate Commerce Commission; it represented the first recurrent swing of the pendulum toward interdependent organization. The commissioners met at Alexandria in March, 1785, and adjourned to Mount Vernon as Washington's guests. Obstacles arose, especially in the prevailing sentiment for supreme state autonomy; and with the view of increasing

both the wisdom and the weight of their findings, they ended by arranging an interstate conference in Annapolis in 1786. Here opinion took shape as to the use of interstate and other waterways (then the sole lines of commercial movement) and as to the interdependence of the states; yet so many collateral questions arose, and so decided need was felt for larger authority, that no final action was taken beyond arranging for a joint convention of delegates from the several states to be held in Philadelphia in 1787. This convention, designed primarily to consider interstate commerce and waterways, took up also other relations between the states; the delegates found themselves confronted by the gravest possible questions affecting the prosperity and perpetuity of their respective communities and commonwealths; they deliberated and gradually adjusted these with intelligence and integrity unsurpassed in assemblages of men—and the outcome was the American Constitution, which made the infant commonwealths a nation.[1]

The work of the first waterways commission is significant in its bearing on later conditions and events—even to-day. In a sense the world was young in 1785; the sum of knowledge was but half, the knowledge of North America hardly a hundredth part, of that now prevailing—yet the original commissioners and first conferees and final delegates all took stock, so well as might be, of state and national possessions as affecting the conditions and prospects for the perpetuity of a growing country. To them and to the people who later adopted their findings land was the primary value, minerals a casual adjunct, forests an obstruction to travel and settlement yet a convenience, water an incident though a means of commerce, riparian rights an abstract albeit obstructive inheritance; and in the light of these views of fundamental values (the essential factors of national growth), certain powers were expressly granted by the people to the federal government, certain rights were expressly given or denied to the states, and any inchoate powers and rights were implicitly reserved for future division in accordance with the eternal principles recognized and set down—and without which were the constitution, in the words of Marshall, "a splendid bauble" (McCulloch *v.* Maryland *et al.;* Dillon's compilation, 1903, p. 277). Perhaps because it was what the great jurist afterward described as the "oppressed and degraded state of commerce" (Brown *v.* Maryland; *ibid.,* p. 539) that led to the creation of the commission and so to the conference and convention, the "commerce clause" of the constitution is notably condensed and comprehensive—so condensed that even within the lifetime of many of its framers the genius of Marshall was invoked to define it in opinions demonstrating that

[1] The chain of events is conveniently summarized by Woodrow Wilson, "History of the American People," Vol. III., p. 60, et seq.

the object of the instrument was to permit rather than to prevent exercise of governmental functions, so comprehensive that it has met and promises forever to meet a growth of commerce transcending the most roseate dreams possible in 1787.

The first-fruit of the constitution was renewed activity in commercial development: Washington's difficulties on the Potomac passed, and he planned an adjunct canal to connect the long-settled tide-water region with the virgin Ohio country beyond the mountains; Dewitt Clinton evolved his then stupendous project of uniting the Atlantic seaboard and Lake Erie by an artificial waterway; and just a century ago Albert Gallatin, sustained by the sympathy of Thomas Jefferson, outlined a plan for waterway improvement and commercial development which in broad adjustment of the means and ends of national development has never been surpassed and seldom approached.

With the conquest of natural power through the control of steam (which indeed led to one of Marshall's masterly interpretations of the "commerce clause") conditions changed, and the railway opened an era in settlement and production such as the world never before saw and may not see again—indeed, while material and immaterial agencies can not well be compared, it is not too much to say that just as the American constitution made our nation, so the American railway made our country a world-power. Population and riches beyond the imaginings of the nation's founders followed and were bound by the iron bands until great commonwealths bridged the continent, until it were easier to think of millions than of thousands before, until one seventh of our swollen wealth came to be railway property and its ownership a factor in law-making, until every-day ideas of domestic travel and transportation came to connote railways alone.

Meantime the prophetic visions of Washington and Jefferson and Clinton and Gallatin faded—for a time. True, the canals projected by the earlier commissioners along the Potomac and connecting Delaware and Chesapeake Bays were constructed, Erie Canal was completed, the Delaware and Raritan, Morris, Lehigh and a dozen others were put into operation—yet they gradually passed into the ownership or controlling influence of railway corporations, and half of them were virtually abandoned. True, the steam packet traffic of the Mississippi and Ohio attained high efficiency and a sumptuousness of appointment starting back-woods simplicity toward culture, while the Missouri was so navigated as to open the opulent storehouses of the vast northwest—yet, as railway enterprise grew and the slip-shod ways of slave-labor passed, the territory was tapped and the traffic transferred to overland lines until river traffic was virtually dead, the water-fronts of every river town from St. Paul to New Orleans (save "Natchez on the Hill") controlled by railway interests, and the once resplendent river

vessels reduced to rattletraps. True, federal provision for river improvement continued sporadically under what was long jocosely styled the "pork barrel" committee, from which the stigma finally faded under the leadership of the stainless and brilliant Burton, until the aggregate expenditures for rivers and canals reached several hundred millions—yet the federal policy remained repressive and commonwealths and capitalists held aloof: there was never a cabinet officer charged with the duty of developing or maintaining commerce by water, the admirable engineer corps was barred from initiative by custom and even by law, the Rivers and Harbors Committee found its chief function in scaling down or turning down estimates and projects presented by the people. Mechanism for progress there was none; of means of repression there were many. And population and production gradually overtook and then outpassed railway capacity.

The Re-awakening

Shortly after the abundant harvests of 1906 were gathered a great popular movement began to stir the interior and the west, and a cry went up against an intangible but real tyranny of transportation that barred produce from markets and withheld supplies from the producers. The movement did not arise in a day; by some it was foreseen for months, by others it was felt only when the pinch of winter came with fuel-famine and need for clothing and transported food-stuffs; yet even by mid-autumn some millions of citizens were astir—far more than felt the thrall of foreign stress a century and a third before. At first the movement was vague and without definite aim; groups met for discussion, conferences were called, complaints were voiced, and then county boards and state legislatures were invoked, and national lawmakers were deluged with appeals from half a million constituents. The situation was simple—within a decade the productions of the northern interior had doubled, while transportation facilities had increased but a small fraction. Fortunately it was sized first by railway men: there were not cars enough; neither were there locomotives enough to move the cars required for the products, nor tracks enough to carry the trains; there were not terminals enough for the rolling stock, nor could these be acquired without imposing a ruinous burden; there was not iron enough in the country to build the cars and locomotives and tracks, not available labor enough to mine and smelt the ore—and besides the cost (estimated, *e. g.*, by James J. Hill at $5,000,000,000 to $8,000,000,000, or one third to one half of our aggregate railway investments) would consume so large a part of our currency as to paralyze other business. Even if the extension were possible, the relief would be but temporary; with normal growth of the country and ordinary increase in production it would be effective for only seven to ten

years. So railway magnates and the masses began to see alike that the congestion of freight was a general condition affecting every industry and the entire country, and one not to be remedied by local and temporary means. Thenceforward discussions and conventions took a definite aim—and for the first time in our industrial history, railway corporations, commercial organizations, producers, and consumers, all united in a common movement for the common good.

Seen large, our primary industries are production and distribution, the latter effected by trade and transportation; and in 1906 it became clear that production had so far outgrown transportation and trade (including every phase of merchandising and banking and broking) as to prevent the normal development of either—*i. e.*, entire sections of the country were confronted by the stern necessity of finding new and more economical transportation facilities, or else ceasing to develop. In fact while citizens and statesmen were seeking facilities and discussing the resumption of water traffic, settlement and production actually stopped over scores of thousands of square miles in the Dakotas, Montana, Wyoming, Washington, Oregon and California: nor can it recommence, save perhaps feebly and sporadically, until transportation is provided. For conditions are changing: In the first place, human nature being as it is, the luxuries of yesterday are the necessities of to-day, so that the time of the independent and self-supporting squatter family has passed, and that of the interdependent settlement or community united on the joint basis of human sympathy and convenient currency has come in its stead. In the second place, water and fuel are no longer mere redundancies if not obstructions to settlement, but essentials to be gained only through collective action. In the third place, the multiplication of communities necessarily involves a much more rapid increase of lines of communication, in accordance with the mathematical law of combination: two communities may be connected by one line, while three communities require three lines; four demand six lines, five need 10 lines, six, 15 lines, eight, 28 lines, twelve, 66 lines; if the lines were not combined, the county seats of a state of a hundred counties would require 4,950 lines of communication to connect them, while the thousand towns of a section would require 49,950 lines—so that a reason for the breaking down of transportation systems in a growing country is the inexorable physical law under which the lines connecting communities increase in rapid ratio. Thus the congestion of traffic in the land of magnificent distances forming the interior and the west in 1906 was inevitable; production and trade had simply outgrown transportation facilities; the railways failed because the marts were too far apart for their carrying capacity—and the old-time packets were gone!

Creation of the Waterways Commission

Of the conventions of 1906, two were especially effective; that of November in St. Louis, out of which grew the Lakes-to-Gulf Deep Waterway Association, and the Washington session of the Rivers and Harbors Congress in December, at which the attendance and interest were beyond precedent. During the latter, strong delegations called on the president, the speaker of the house, the chairman of the Rivers and Harbors Committee; and later the Lakes-to-Gulf Deep Waterway Association led in petitions to the president from organizations of citizens in the interior to "appoint and empower a commission or board of five persons to prepare and report a comprehensive plan for the improvement and control of the Mississippi River system and other inland waterways in such manner that the rivers of the country may be fully utilized for navigation and other industrial purposes." Meantime the Rivers and Harbors Committee reported a bill providing for a somewhat similar commission, though in the pressure attending the closing days of a short session it failed of final action. A score of petitions reached the president during the first week of March, 1907; and on March 14, after combining the two movements toward the same end, he created the present Inland Waterways Commission of nine members, through an instrument of signal vigor and originality:

> In creating this Commission I am influenced by broad considerations of national policy. . . . Our inland waterways as a whole have thus far received scant attention. It is becoming clear that our streams should be considered and conserved as great natural resources. . . . The time has come for merging local projects and uses of the inland waters in a comprehensive plan designed for the benefit of the entire country. . . . The task is a great one, yet it is certainly not too great for us to approach. The results which it seems to promise are even greater. . . . The present congestion affects chiefly the people of the Mississippi Valley, and they demand relief. When the congestion of which they complain is relieved, the whole country will share the good results. . . . It is not possible to frame so large a plan . . . for the control of our rivers without taking account of the orderly development of other natural resources. . . . The cost will necessarily be large, . . . but it will be small in comparison with the $17,000,000,000 of capital now invested in steam railways, . . . [which] investment has been a constant source of profit to the people, and without it our industrial progress would have been impossible.

These fundamental utterances, with requisite explication of details, outlined a policy to which people and press responded with enthusiasm.

The commission began active work on the Mississippi in May, followed by inspection trips through the Great Lakes and down the Mississippi and lower Missouri in September and October. They were accompanied by the president from Keokuk to Memphis in what was designed as a simple inspection yet proved to be at once the most notable pageant in the history of the Mississippi Valley and the most impressive demonstration any president ever saw—for in addition to the

fact of his presidency, Theodore Roosevelt was as a Moses leading the people from an "oppressed and degraded state of commerce" in which they found themselves beleaguered, as did their forebears a century and a quarter before. Nearly all the water craft of the river system were assembled; railways abandoned schedules and stopped freight traffic to accommodate specials; entire towns were evacuated that the inhabitants might gather on the river front. On the average each river town—Keokuk, Quincy, Hannibal, Louisiana, St. Louis, Cape Girardeau, Ste. Genevieve, Cairo, Memphis, and the rest—showed more spectators standing out to salute the presidential party than its entire population; while day and night the air was rent with acclamations of voice, steam whistle, shrieking siren, salvo of guns, and roar and rattle of fireworks.

Individual members of the commission, singly or in groups, studied the Ohio, the upper Missouri and its tributaries, the vast Columbia Valley and Puget Sound, the California rivers, Rio Colorado, the streams of the Gulf slope, and the waters and projects of the Atlantic slope. And the interest of citizens grew in every state, until the autumn of 1907 produced such a crop of conventions and such a volume of support for waterway improvement as no other peaceful issue ever evoked. The Irrigation Congress in Sacramento in September; the Lakes-to-Gulf meeting at Memphis, the Upper Mississippi Improvement convention at Moline, the Interstate Waterway convention at Victoria (Texas), and the celebration of the opening of Hennepin Canal at Sterling, in October; the Trans-Mississippi Congress at Muskogee, the Atlantic Deeper Waterway conference at Philadelphia, the Drainage Congress at Baltimore, the Gulf State Waterway convention at Birmingham, and the Ohio Improvement Association meeting at Wheeling, in November; the National Rivers and Harbors Congress at Washington in December—these were among the national or interstate conventions devoted either primarily or secondarily to waterway improvement and attended by hundreds or thousands of delegates from every state and territory and representing every industrial and public interest of the country during the closing months of 1907. And state executives have commenced to combine not only with their constituents but with each other; at Sacramento there were five governors, at Memphis eighteen, at Muskogee and Washington half a dozen each and at several others from one to three.

Nor is this the end: Under their broad instructions the commission found it needful to consider not merely the improvement of our rivers but the use and conservation of related resources; and deeming the proper administration of these a duty devolving jointly on the nation and the states, they asked the president to follow Washington's example by invoking the advice of our several co-sovereignties in a conference on

the conservation of natural resources. Acceding to the request, the president has invited all the governors of states and territories (each with three advisers) to convene in the White House in May next and discuss ways and means of conserving the waters and other resources of the country with him and with those cabinet officers, justices of the supreme court, senators, and representatives whose duties may permit attendance—and nearly all the executives have already accepted and named their coadjutors.

So the events of the young century strikingly duplicate those immediately succeeding American Independence: Again questions of commerce and interstate relations have become paramount—and in multiplied magnitude and complexity; again it has become necessary to take stock of those material possessions on which the perpetuity of our people must depend—though now the possessions comprise not only the land areas contemplated by the founders but the still greater values residing in waters and woods and mines and soils, which were inchoate then but have come into actuality and dominance through the natural growth and orderly development of the nation; again it seems necessary for a waterways commission to appeal from its own court to an interstate conference representing that highest tribune, the people—though now the appeal can not result in a federal constitution (which came from the former in such perfection as to meet all later needs), yet can hardly fail to bring about a closer readjustment of the magnified sovereignties and multiplied possessions developed on that fundamental platform. The president has expressed the feeling that the May conference promises to be one of the most important assemblages in our history; and the people and the press have concurred with a unanimity seldom evoked, and giving assurance that the anticipation will be realized.

Nor is it to be forgotten that in advocating the development of our natural channels of commerce, Roosevelt is but following the footsteps of Washington and Jefferson, and Root but treading the path blazed by his early predecessor Gallatin; though they are supported in cabinet, notably by the progressive Secretaries Garfield and Wilson, far more vigorously than were the pioneers—indeed, never before have a people and an administration been so firmly united in efforts to improve an "oppressed and degraded state of commerce" with the attendant conditions of national prosperity.

The Need for Navigation

The most pressing demand of the day connected with our inland waterways is for navigation and carriage of freight. The need is urgent. The notably reserved and cautious Interstate Commerce Commission has just declared:

It may conservatively be stated that the inadequacy of transportation facilities is little less than alarming; that its continuation may place an arbitrary limit on the future productivity of the land; and that the solution of the difficult financial and physical problems involved is worthy the most earnest thought and effort of all who believe in the full development of our country and the largest opportunity for its people.

While we now have 26,200 miles of navigable rivers and some 2,800 miles of canals in operation (with nearly as much more inoperative or abandoned) which during 1904 carried, respectively, 127,000,000 and 5,000,000 tons of freight, we have also 222,500 miles of railways which during 1906 carried 1,631,374,219 tons—*i. e.*, although the United States has a more extensive and better distributed natural system of inland waterways than any other country, and despite the fact that water carriage costs on the average but a third or a fourth as much as rail carriage, less than one ninth of our freight lines are waterways, and only one twelfth of our commodities are carried by water. And of our aggregate assets of say $107,000,000,000, our steam railways have risen to some $16,000,000,000 or $18,000,000,000, or nearly one sixth, which even at first sight seems out of proportion; and the disproportion becomes still more glaring when current production is compared with railway earnings—the former in 1906 reaching $7,000,000,000 to $10,000,000,000 (according to mode of estimate of farm products) and the latter $2,325,765,167, or fully one fourth as much. The case is clear; we are employing extravagant agencies and paying exorbitant rates for transportation; the prices of our staples depend too little on cost of production, too largely on cost of carriage.

The condition is not new, only grown worse yearly; it led largely to the establishment of the Department of Commerce and Labor, and wholly to the creation of some of its bureaus; it has led to legislation in several states, and thence to conflict between state and federal authority in a number of cases; and above all else it has led to such paralysis of settlement and production as to check the growth of the country. In a dozen states the "oppressed and degraded state of commerce" is not an idle phrase; it denotes a condition now intolerable, and soon to be suicidal unless relieved, and that by measures both prompt and permanent. Our productions are ample and our ports sufficient to maintain a beneficial balance of international trade; yet products and ports were but a burden unless the one can be laid down at the other at prices permitting interchange with the rest of the world. Our Panama Canal is a gateway to the nations—yet of what profit to us unless our exports can be delivered on the sea-board at a competitive figure, *i. e.*, at a reasonable increase on the cost of production? The time has come to inquire whether Boston, New York,

Philadelphia, Baltimore, New Orleans, San Francisco, Portland and Seattle are to be gateways for growth or mere leak-holes of national wealth; whether the advantages of great-circle steam-lines may not overbalance productivity and transfer dominant commercial lines and centers beyond our boundaries; whether we are able to balance our magnificent distances and splendid productivity in such wise as to maintain that economy of transportation and reasonableness of delivery of both imports and exports requisite for a world-power! The questions are nation-wide. Twenty-odd states and forty million inhabitants of the interior are actually suffering from the congestion; fifteen states and thirty million people on the Atlantic coast are complaining under imposts of burdensome traffic; the western states with their seven millions, which would triple in ten years were the burden removed, find their growth paralyzed by the same cause.

Will the improvement of waterways and the restoration of water traffic bring relief? Certainly the plan promises much, while no other promises anything. It has been estimated that our 29,000 miles of inland waterways (exclusive of lakes, bays, sounds, etc.) might be doubled at a cost of $500,000,000 to $800,000,000,[2] *i. e.*, one tenth of the amount required to raise railways to the capacity required to-day; and it is safe to say that when the nation adopts a progressive waterway policy, private enterprise will build the boats—and that when this is done our great productive areas can deliver exports at and receive imports from the coast cities at an average of not more than half and probably less than a third of the present cost. With the readjustment of transportation lines, the railways might change from trans-continental carriers of bulk freight to feeders of the waterways; yet their efficiency as public utilities need not decline, and their profits might increase, as recently held by President Harahan (of the Illinois Central Railway). The superior economy of water transportation, which has been shown statistically over and over again, may be illustrated by the fact that a river packet can be built at a cost of two miles of railway (including rolling stock but not right-of-way or terminals) and will carry three 400-ton train-loads of freight; or that a tow and barges suited to the Mississippi-Ohio traffic can be built for the cost of four or five miles of railway and will carry 150 train-loads; or that the entire cost of waterway development contemplated would hardly suffice to build and equip a single trans-continental double-track railway with the requisite rights-of-way and terminals.

Nor is waterway improvement a new venture, involving unknown

[2] The Bartholdt bill now before the house of representatives provides for a bond issue of $500,000,000 for waterway improvement; the Newlands bill pending in the senate provides for a waterway fund of $50,000,000 to be continued by appropriations or bond issues as needed.

factors: Many of the problems were solved practically by Washington and Clinton and their contemporaries through canal systems that would unquestionably be in use to-day had not the railways better met temporary needs; most of the rest have been solved in European countries that are to-day better advanced than ourselves both in waterway development and in that adjustment of transportation to production on which national prosperity must depend. In the light of this experience it would seem easy to return to and perfect Gallatin's great waterway system; and in the light of present needs, it should begin in the interior with a deep channel from the Great Lakes to the Gulf, and in the East with an Inner Passage from Massachusetts to Florida—and these main arteries should be coupled with passages skirting the Gulf coast and with improved tributaries in such manner that standardized barges may pass from Benton to Boston or to Brownsville, or from any lake port to any sea port with some choice of routes: and eventually through the Minnesota and Red River of the North to Lake Winnepeg and Hudson Bay, in order that the grain-fields of the Canadian plains may find outlet to the sea during a longer open season than that of Hudson Strait. And at the same time the pressing need of the Pacific Coast should be met; the treasure-houses of the Columbia and Snake should be unlocked and a way made into Puget Sound, while the golden gardens of California Valley should be opened to ships going down to the sea in order that the grains and fruits now rotting in bin and on branch may be turned to human good and national welfare. The details are innumerable; the demands irresistible.

Among the waterways, three or four should be improved not merely to meet commercial needs, but as a patriotic duty: First in importance is the Lakes-to-Gulf project; for should disaster befall and Canada pass into unfriendly hands, the enemy might within a week put war vessels into the Lakes through Welland Canal or the still larger Huron Canal (of which we hear little thus far), in which case catastrophe could be averted only by a waterway of war-ship capacity from the Gulf to Lake Michigan. Scarcely less important is the protected passage projected for the Atlantic slope, though since the baseless Cervera scare the details need not be pursued; while the connection of the Columbia with Puget Sound, and the extension of San Francisco and Suisun bays need no more than mention in connection with the military possibilities of the day and the "national defense" of the founders.

The Value of Water in Itself

While navigation is the most pressing use for our waterways, there are others of no less present value and future promise. Neither Wash-

ington's waterway commissioners nor their successors took much account of water save as a way for commerce; they failed to recognize water in itself as a resource and hence an object of property, except vaguely under the imported common-law notion of riparian rights—*i. e.*, rights vesting essentially in the land with the water as an appurtenance thereto. Now as settlement extended into the arid regions, the pioneers learned through the bitterest experiences within human capacity that water itself is a primary value, indeed the greatest of all values; and gradually a new concept arose, under which individuals, then communities, and finally (in some cases) states came to recognize actual ownership in water.[3] As the concept took form it became clear that the value of land itself—the chief value reckoned by the founders—is determined chiefly by the water on or in its substance, for if too wet it is worthless, if too dry a menace to life; indeed the market value of each acre of arable land in the United States to-day is determined within some ten per cent. by the associated water—*i. e.*, the water-value is nine when the land-value is one.

The new concept of water as a primary value in its substance or corpus is not yet crystallized in statute or even in custom; it has come up with the natural growth and orderly development of the country; and it is still an open question whether the powers of the states or of the nation are paramount—though the view that the value pertains to the people and is to be administered primarily by the nation on account of its interstate quality, and secondarily by the states as an appurtenance of the land, would seem to accord with the principles framed into the constitution and interpreted by Marshall and contemporary jurists. Certainly a value of such magnitude as the 40,000,000,000 cubic feet of water flowing annually down to the sea is a natural resource too closely connected with the peace and perpetuity of the nation to long remain neglected; it alone would warrant conference between the executives of state and nation. It is within the memory of many now living that a man able to estimate the value of a raft of logs or a patch of standing timber more closely than his fellows, taking advantage of the fact that forests were still regarded as little more than obstructions to settlement, began to buy small tracts nominally as land but actually for the timber, and continued turning over his growing capital and buying larger and larger tracts as the pineries were despoiled, until he became an undercurrent of power in legislative halls and at last gained wealth probably exceeding that of any other individual in the world's history; and he but exercised prevision in taking freely that which was not at the time regarded as a

[3] Summarized by Hess in "An Illustration of Legal Development—the Passing of the Doctrine of Riparian Rights" (*Am. Polit. Science Review*, Vol. II., November, 1907, pp. 15–31).

value. Now, the vast inherent value of our forests is but a bagatelle in comparison with the inherent value of our living waters; the time is ripe for taking stock of this immeasurable resource; and it behooves the people through the representatives in whom they repose confidence to claim this greater heritage on which the lives of the generations must depend.

The Utilization of Power

An ill-recognized value of running water resides in its power, a quantity doubtless sufficient to drive mills and trains and boats, and furnish light and heat and domestic motors for a century or two after our coal is gone. Hitherto this resource has been neglected, partly because the concept of inherent or potential value remained inchoate, and power was not felt to exist until actually developed by dams and races and penstocks; yet the realization that 40,000,000,000,000 cubic feet of river water descending an average of 2,500 feet is a rich possession can not long be delayed, for it exceeds 300,000,000 horse-power, or thrice the pulling power of all the horses now living in the world—even if the sum be tithed for safety it will still reach 30,000,000 horse-power, which at $20 per year would be worth $600,000,000 annually (or more each year than the estimated cost of improving all the rivers of the country), equal—at 3 per cent.—to a capital of $20,000,000,000. And the availability of water-power entered on a new era with the perfecting of electrical transmission in the last decade!

Though the time is not ripe for discussing utilization, a case may be instanced: The boldest water-supply project in our history was undertaken when Los Angeles, a city of only 150,000, bonded itself for $23,000,000 to purchase a riverlet 250 miles away; it seemed an appalling price for continued civic life, yet the people were ready to pay; and it was not until the plans for piping were nearly done that the incidental value of the power was realized—and negotiated at rates yielding ten per cent. on the bonds! Suffice it to add that even if the improvement of our waterways for navigation were to cost five or ten times the amount estimated, the water-power developed incidentally in connection with the works, if judiciously administered, would alone pay the entire cost in from five to twenty years. Picturesque streams and cataracts should be saved as scenic features, for natural beauty is a national asset beyond material measure; but the ignoble wild should be harnessed to the plow of progress.

Fortunately, while the founders failed to define the proprietary interests in the running waters, they recognized their interstate character and granted the nation certain authority over them; and this has been repeatedly confirmed by the courts and crystallized by statutes

authorizing the retention of rights in power developed by private means, the time limitation in grants for state or private works, and the leasing of power developed on public works.

Land Waste and Reclamation

Each year the rivers of mainland United States pour into the seas a thousand million tons of richest soil-matter in the form of suspended sediment—an impost greater than all our land-taxes combined, and a commensurate injury to commerce in the lower rivers which are rendered capricious and difficult of control by the unstable load. Moreover, the greater part of the sediment is swept down during floods which annually destroy and depreciate property to the average value of scores if not hundreds of millions, besides preventing development of the fertile lowlands; and furthermore, expert determinations show that the organic contamination of running water varies directly with the suspended sediment, so that muddy water is a common cause of disease and death. Now any comprehensive plan for waterway improvement will necessarily involve prevention of floods by means of far-sighted forestry, intensive farming, judicious reservoir-construction, and other devices whereby the waters will be compelled to flow even clearer and purer than they did before nature's delicate balance between rainfall and slope and natural cover was disturbed by settlement and industry. It is conservatively estimated that the benefits resulting from the clarification and purification of the water will in themselves balance the entire cost of the system of waterway improvement required to relieve the existing congestion of traffic.

And the control of the waters involves reclamation of arid lands by irrigation, and of certain swamp and overflow lands by drainage. It is estimated that these means, extended to projects already in sight, will fit 150,000,000 acres of highly fertile land for settlement, thereby furnishing (in forty-acre farms with necessary villages) homes for an additional population of 20,000,000—or four times that number under the intensive culture which finds "ten acres enough." The expense involved might by judicious administration be made incidental to that required for improving the waterways for navigation (which would hardly exceed that of a trans-continental railway line), while the direct benefits, as illustrated by the operations of the U. S. Reclamation Service to date, would amount to many times the cost.

Development and Conservation

Such are some of the conditions and values brought into view by the recurrent congestion in transportation—for which relief is imperative, else the nation must sacrifice its supremacy and by reason of

its own bigness yield the van of progress to lesser contemporaries. The cost of relief will be large, as the nation is broad and its productions opulent; yet from the standpoint of traffic alone the game will be worth far more than the candle. In addition, the prevention of soil-wash and the purification and clarification of the streams will, as the value of water increases with multiplied population by natural growth and orderly development, more than balance the entire cost; if the works be planned to utilize the incidental water-power, it alone will (with a moderate working capital) not only pay the entire current cost but replace our rapidly decreasing mineral fuels as a source of energy; and a dozen incidental advantages and values clamor to be entered on the credit side of the ledger. Eventually, if not to-day, the nation must take stock not merely of its land but of the 150,000,000,000,000 or 200,000,000,000,000 cubic feet of water annually falling from the heavens on the 2,000,000,000 acres of that land and giving it value—must conserve and control the boon in such manner as to minimize destruction and loss and maximize benefits for citizens and country: and any present step should take the right direction. Other resources, too, demand conservation—especially the timber and coal and oil and iron supplies already largely gone. The sole obstacle to-day is precisely that which confronted Washington and his contemporaries in the earlier waterway agitation—the doubt as to who should act in the public interest. The obstacle was overcome one hundred and twenty years ago: Can its present phase then deter the nation made great by the infant effort? That is the question to be weighed by the executives of states and nation in joint conference in the White House next May.

Fortunately the later statesmen hold a point of vantage; for America has become a nation of science. The sum of knowledge has gained a hundred per cent. and knowledge of the country and its resources has grown a hundred fold since 1787. The lands have been explored and surveyed; the mines have been opened and tested; the rainfall and rivers have been measured; several of the sciences have taken form and placed facts and principles at command; and under the stimulus of a far-sighted patent law invention has harnessed natural forces in a manner inconceivable even a century ago. The early ideas were of extension and diffusion; the present needs are for intensive development and conservation. And while the later stress may be less than the earlier it is attended by wider experience and surer modes of thinking, so that action ought to be easier and safer. Certainly the stress will increase until relieved; and there are those who feel that the present issues and the prospective conference may well mark another epoch in national policy and national growth.

ACCIDENTAL RESEMBLANCES AMONG ANIMALS. A CHAPTER IN UN-NATURAL HISTORY

By Professor BASHFORD DEAN
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THE naturalist of to-day is perhaps unduly saturated with the belief that animals and plants adapt themselves to their surroundings. He has seen so many and such admirable examples of this, and in every field of his work, that he is apt to conclude that the principle of adaptation can be called upon to explain phenomena which when critically considered may prove to be not adaptive at all. In the familiar case of an insect whose colors suggest lichen-covered bark, or a dead leaf, or a flower, we have come to conclude, since we have seen many examples of demonstrated utility, that the resemblance is significant, that it protects the insect against its enemies and that it has been the outcome of a series of evolutional changes which have made the protective coloration more and more complete. We have even reached a point, some of us at least, where we neglect to scrutinize the evidence that the creature in question frequented the kind of bark, leaf or flower which it resembles, or that, if it did, it was thereby protected so completely as to ensure its survival. We have reached the point, to make this attitude clear, when we hold up before our students a butterfly mounted on a twig and point out the marvelous "protective" resemblance between the butterfly and the neighboring pressed leaves, without suspecting that the leaves belonged to a beech tree "made in Germany," and that the butterfly came from the East Indies!

So also is our attitude a lax one in the case of animals which resemble other animals and are thereby protected, like moths which resemble wasps, flies which can be mistaken for bees, butterflies which are similar to butterflies known to be rejected by birds, etc. For we have seen so many instances of undoubted mimicry that we are apt to accept resemblances as of this type, even if they have not been experimentally demonstrated. That such accurate resemblances, on the other hand, could occur even in animals which live side by side *and yet mean nothing*, would be something of a heresy to many evolutionists. Yet I am inclined to believe that this is a fact—although to prove this in concrete instances would be at the moment difficult. However, it can, I think, be established indirectly and by striking analogies. For if there occur among animals numerous resemblances which mean nothing, we may justly be skeptical of other resemblances—unless their value can be experimentally proven.

In point of fact, if we sift out the cases in which mimicry and protective coloration have been demonstrated beyond question, we find that their number is by no means as large as we at first assume. And of the remaining cases, probable, or imperfectly proven, we should, in fairness, leave open the possibility that what seems protectively colored or mimetic resemblance might in the end turn out to be accidental and meaningless. And in the present notice it may be interesting to refer to these meaningless resemblances in order to show both that they are abundant, and that they are excessively complicated—in certain cases, even more complicated than those which are commonly regarded as typical, if not brilliant instances of protective or mimetic adaptation.

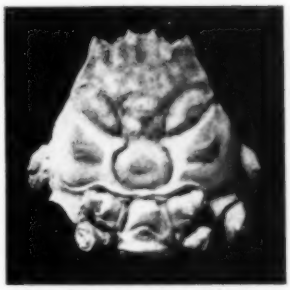

FIG. 1. CARAPACE OF A JAPANESE CRAB, *Dorippe* picturing in relief an oriental face.

FIG. 2. WHALE'S "EAR-BONE" which in profile suggests the face of a Scandinavian fisherman.

As an example of a meaningless resemblance let us first refer to the Taira-crab, a *Dorippe*, Fig. 1, on whose back a human face appears strikingly portrayed. This crab occurs rather abundantly in a region of the Japanese coast where many centuries ago a great naval battle took place: and *it was only after this time*, local Buddhistic tradition states, *that a face of a Taira warrior appeared on each carapace*, as tangible evidence that the souls of the dead migrated into the bodies of these lower animals![1] Now, the resemblance in this case is developed to an almost uncanny degree; the face, first of all, is clearly oriental—even more Chinese or Corean in type than modern Japanese, but from this very fact the more singular, since at that time but few

FIG. 3. OCCIPUT OF GOAT'S SKULL, showing face of Hanuman monkey.

[1] A.D. 1184, at Dan-no-ura, the Taira clan was exterminated by the rival Minamoto headed by Prince Yoshitsuné.

Ainos had been absorbed into the Japanese race, and its physical features were therefore, on historical evidence, more strongly continental. The face, in the second place, is that of a drowned man: it is horridly infiltrated, the nose swollen and the mouth widely opened. In such a case the complicated nature of the meaningless resemblance can hardly be overestimated. For we have in it, as will be seen, a series of resemblances which are added one to the other, from the general to the specific, in somewhat the following way: human face (in itself, of course, a very complicated structure) : male: young: oriental: primitive Japanese: drowned.

A second meaningless resemblance is shown, Fig. 2, in a whale's "earbone" which was found on a beach in Norway: it portrays in half relief a Scandinavian face of low caste, and with almost absurd accuracy—with rounded cheek-bones, flattened nose-bridge, small upper lip and receding jaw.

In both of these cases there is an extraordinary meaningless correspondence between the resembling objects and the especial locality in which they occur. And this condition occurs with amusing frequency.

A case in point occurs in the skull of a goat, Fig. 3, picked up in Agra, which shows on its supra-occiput the face of the common monkey of the locality, the Hanuman (*Presbytes entellus*), for it shows (with a slight tax on the imagination) the front view of this monkey's forwardly directed beard, cheek-tufts and brow-hair, and these, too, in light tone against the dark-colored face.

Another possible case is that of the squash seeds, Fig. 4, which in drying acquire irregular depressions on their surface, and thus produce

FIG .4. SQUASH SEEDS PICTURING IDEOGRAPHS.

the effect of idiographs. They are said to have come originally from Japan, but in any event so perfect are the "characters" that I have known a Japanese scholar to puzzle over them for several minutes in his effort to read them!

A somewhat analogous instance, Japanese (noted by my friend, Dr. Yatsu), is that of the "Tokugawa fish," a small species of *Salanx*, which is said to have appeared in Yedo (Tokyo) shortly after the last dynasty of regents made their seat there. This fish is curious in that its head bears the badge of the Tokugawa family, the three *Asarum*

leaves conjoined. This effect is produced by the lobes of the brain, which can be clearly seen through the transparent headroof.

An example which pictures a human face almost as strikingly as in the Taira crab is seen in the chrysalis of the butterfly, *Feniseca tarquinius*, Fig. 5.[2] For here the resemblance is developed in remarkable

FIG. 5. PUPA OF THE BUTTERFLY, *Feniseca tarquineus*. (Cut loaned from *Entomological News*, through the kindness of its editor, Dr. Skinner.)

detail, with forehead wrinkles, eyebrows and lids, aquiline nose, thin determined lips and straight mouth—all in this case as palpably Caucasian as the Taira face was proto-Japanese. If the present photograph had been taken from a larial mask of Tarquin himself, it could hardly appear more human!

A second pupa-portrait is given in Fig. 6, in the case of *Spalgis Ssignata* Hol. In this instance not only are the characters of Feniseca paralleled, but there appear hair (frankly not a vast chevalure) on the "head," pupil in the "eyes," and the general appearance in grotesque of the head of a chimpanzee. Not remarkable, therefore, that the habitat of the "mimicking" insect is West Africa!

A third pupa portrait, Fig. 7, again a Feniseca,[3] but I do not know

[2] For the permission to use this figure, and the loan of the cut itself, we are greatly indebted to Dr. Skinner, the editor of the *Entomological News*.

[3] For this I am indebted to Professor Wheeler.

of what species, is taken from a photograph of a dried specimen. It has the face-like appearance, and suggests amusingly the restoration of the *Brontosaurus,* in the American Museum.

Still another meaningless resemblance is in the death's head moth, *Acherontia atropos,* which shows a "remarkably faithful delineation of a skull and bones upon the back of the thorax." And in allied species the skull is even more sharply pictured—in *A. lachesis,* for example, where it appears in minature size.

FIG. 6. PUPA OF *Spalgis,* showing "monkey face." (From figure published, 1892, in *Psyche.*)

A less familiar case, and as obviously meaningless, is the resemblance to a cuttle fish, which one finds in the end view of the larva of the crane-fly, *Tipula abdominalis,* Fig. 8. This appearance might conceivably inspire a wholesome dread among some marine creatures—but the fact remains that the present larva lives in wet rotten wood (or under ground) where an octopus-like resemblance could not benefit it. Indeed among insects one may find numerous instances of accidental resemblances. Some pupæ we have already referred to. Others, bombycids, for example, suggest mummy cases, the region of wings, antennæ and tongue, picturing both in form and proportions the Egyptian head-gear and beard. It is improbable, to say the least, that the Egyptians arrayed their dead after the fashion of a pupa to encourage a teleological analogy, for one reason, since the headdress and beard were displayed in a similar fashion during the lifetime of the individual. Striking, too, are pictures which one sometimes finds on the wings of butterflies—among these, as Mr. Beutenmüller showed me, are the heads of French poodles, which appear *en silhouette* on the wings of the orange-colored butterfly, *Colias* (*cæsonia* and *eurydice*). And on the hind wings of the ragged butterflies (*Grapta*), as every one knows, appear commas and semicolons printed in silver upon an otherwise dull-colored wing. In the group of bugs (Hemiptera) one recalls the initial W, which occurs in certain cicadas, and there is the interesting case of the tree-hopper, *Membracis binotata,* to which Professor Wheeler drew my attention. This tree-hopper and its young

FIG. 7. PUPA OF *Feniseca* SP., showing "face."

represent amazingly "a family of tiny birds with long necks and swelling breasts and dropping tails, verily like an autumn brood of bob-whites" (W. H. Gibson), Fig. 9. Had they been twenty times their present size they might have run the risk of being described as mimics!

Among other resemblances of this nature one recalls the spectacles which appear on the neck of the cobra. Then there are the insect,

FIG. 8. "OCTOPUS" SHOWN IN HINDMOST ABDOMINAL SEGMENTS OF THE LARVAL TIPULA.

monkey and human figures in orchids and in various other plants, pictured in flowers, parts of flowers and in fruit. The last sometimes give striking and grotesque forms, as in the case of our common garden snap-dragon, Antirrhinum. Here, Fig. 10, the seed pods look like diminutive human heads which are arranged on the stalk in a way which suggests the poles-of-skulls, or "medicine" ornaments of certain savages. Peculiarly perfect is this resemblance, for there are pictured not merely the cranium and face, but the dried and weathered portions of scalp, eyelids, lips, as well also as temporal sutures. The color of these seed pods, furthermore, is strikingly like that of mummied heads. Meaningless resemblances occur also in various bones, as in the case of the goat skull or the "ear-bone" noted above. Thus, as Hugh Miller long ago discovered, there is a curious human figure in the cranium of a Devonian fish, and the rabbit, even when "dead and turned to dust" is not free from its arch-enemy, for its sphenoid (Fig. 6) pictures the head of a fox so cunningly indeed that this bone has long been used as a scarf ornament for the English hunter.

Instances of this kind need hardly be multiplied. They extend on every side in the inorganic as well as the organic—from the simple cloud figures conjured by Aristophanes or the various forms of weathered rocks (like the "camel of Brignogan"), to the most curious and complicated.

In short, therefore, it is clear that if meaningless resemblances are numerous and striking, one can accept protective resemblance and mimicry only in instances which have been fully demonstrated. And we may in the meanwhile mark as doubtful numerous cases which now pass current in zoological literature. Among these would, I believe, fall the famous leaf-like butterfly, *Kallima,* which Weismann has adopted as the ne plus ultra of protective resemblance, for in the lack of adequate experimental evidence even this form may prove to be a meaningless resemblance, and not the product of selection. That it may be, and probably is, of protective value at the present time can as readily follow from an accidental resemblance which happens to turn out to be valuable as from one which has been the product of

FIG. 9. TREE-HOPPERS WHOSE APPEARANCE SUGGESTS BIRDS. After Gibson in *Century.* (Cut kindly loaned by Dr. Skinner.)

numberless selected variations. In fact, it is quite credible, it seems to me, that accidental favorable variation may have furnished the basis of many a useful resemblance—as some mutationists believe. And there are no peculiar "adaptive characters" in *Kallima* which can safely be construed as more complicated than the meaningless characters of the Taira crab. For in what way is the resemblance of a

butterfly with folded wings to a leaf more remarkable than the appearance of a human face on the back of a crab? For the contrast, when dissected, would give us in the one case the characters—leaf-shape, color, midrib, reversed markings (veins) on one side of midrib, concealed legs and antennæ, "petiole," and fungus-like patches, as opposed, in the case of the crab, to the equally complicated characters—human face, color, young, oriental, primitive Japanese, drowned. It is only fair to conclude, therefore, that if a meaningless variation can produce the Taira crab, it might equally well have produced *Kallima*.[4] The conclusion, indeed, that Kallima formed the apex of a series of selected changes, is, on our present evidence as to the habits of this insect, hardly different in kind from the assumption that the present perfection of the skull on the death's head moth is the result of selective

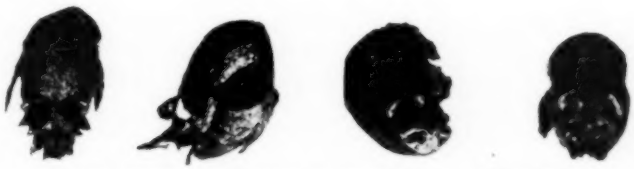

FIG. 10. FRUIT OF THE GARDEN SNAP-DRAGON, *Antirrhinum*.

changes, through whose agency this form came gradually to be avoided and thus secured immunity from, by superstitious man, an important enemy! In fact, in this case, there is actually a stronger body of evidence that the moth is avoided by man than that Kallima is overlooked by birds.

In a word, it is a fair conclusion that our notions of protective resemblance and mimicry are carried in numerous instances farther than the law allows. And one does not have to go far afield for cases in point. Thus the snake's head which is pictured on the wing tip of an East Indian moth, *Attacus atlas*, does not strike one as a convincing case of mimicry, in spite of Weismann's arguments. It is true that the snake is strikingly portrayed, both in color, poise and expression, and we will readily admit that it *might* give a wholesome jolt to some enemy of the moth which happened to see it just at the right angle. But the picture in this instance is not more striking than many of the meaningless resemblances we have quoted (*e. g.*, the French poodle pictured on the wing of Colias), and I think we may reasonably demand definite experimental proof before accepting the "mimicry." In certain other instances one can not feel assured that the resemblance is of actual value to the "protected" form. As an instance of this,

[4] In this connection, *cf.* a note in *Science*, Vol. XVI., p. 832, in which the present writer comments upon the scantiness of evidence as to the protective value of the characters of *Kallima*, and notes the appearance of this insect on and near leaves which it in no way resembled.

I recall the living *Ichthyophis,* the curious burrowing salamander, which I once had the opportunity of observing in Ceylon. This is surprisingly like a worm in many regards, yet a mimic it can not be, since it could derive no profit from the resemblance, the worm being infinitely less protected than itself. If any mimicry could exist in this case it is clearly in the opposite direction, the worm mimicking the salamander, but this possibility is precluded since the mimicking form is infinitely more plentiful than the mimicked, and, most significant, neither form is apt to expose itself in a light where the resemblance would have any value. None the less the mutual resemblance is quite striking—in shape, proportions, size, color, annulation, movements, position of vent, etc. Yet we can only interpret it as due to parallelism. And if this is the case, may not parallelism, *i. e.,* similarity in structures due to similarity in habits, not mere accidental resemblance, be taken as a further danger in interpretation.

For the rest we may query, as others have done, whether the importance of protective coloration and mimicry may not be still further diminished when we eliminate our anthropomorphic conception of the senses of the lower animals. For we may reasonably harbor the suspicion that colors and patterns, which to man seem protective, are by no means as valuable as protection against the keener and more specialized visual impressions of the lower animals. For just as "scent" perception in certain invertebrates, as in various moths, is immeasurably refined, far more so than we are in the habit of conceiving the scent-sense, so also there may have been developed a special sense for detecting the most subtle differences in color, texture, form in those animals which prey upon mimetic and protectively colored forms. Indeed, such a view is the less unreasonable when one considers the condition of the optic centers and end organs in those vertebrates, teleosts, reptiles, amphibia, birds, which have most to do with creatures in which protective coloration and mimicry is supposed to occur most abundantly. And it is not beyond the pale of possibility that the predatory forms have evolved habits in connection with sense-organs which would cause them to distinguish more promptly the protected forms than those having bright and obvious colors. It is in this direction that we have need of close observation and critical experiment.

THE HISTORY OF SCIENCE—AN INTERPRETATION

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IN the recent discussion of the ways and means of making more efficient use of science in educational work, one suggestion keeps coming repeatedly to the front—perhaps more frequently than any other. It is this: That the history of science be made more prominent in the course.

This suggestion has been made from a number of different points of view. For example, some claim that the stories of the lives of the heroes of science furnish powerful stimuli toward arousing interest in and enthusiasm for the study of science. Others urge that the history of inventions may be used to great advantage in linking work in science with social and economic life, thus adding a touch of human life to an otherwise rather abstract and impersonal subject. Still others hold that scientific concepts can not be clearly formed without tracing them from their origin through their development to their present condition.

The importance of recognizing that science is not ready-made, fixed and finished in form and matter; the delight that young people feel when they are shown that the field is open before them, so that they too have a chance to help in the building up of science; the pleasure of knowing that he who works in science is dealing with a growing thing—all of which may be obtained from a study of the history of science—are all put forth as reasons for our paying attention to this side of our work. To one who thinks over these various suggestions, it must appear that they are not independent of one another. Hence, because of the growing importance of this matter of history of science, it becomes of interest to see if a more general justification for its introduction can not be found—one that includes all the others as special cases, and at the same time points out the way in which this history should be handled to enable it to produce the most valuable results. If we would attempt to do this, we must first agree on what we mean by history, and what by science; since each of these words covers such a multitude of sins that its meaning is not sufficiently definite for our purpose.

I. The history whose study lends power to the teaching of science is, naturally, not the thing that is popularly known as history; namely, political history. It is evidently of small interest to science

to know to which royal family the king at any given period belongs; nor is science particularly concerned with the list and the peculiarities of the wives of Henry VIII. Science does not even care tremendously whether Marie Antoinette spent her summers at Versailles or at Medicine Hat; nor yet whether the jewels of the mother of the Gracci were real diamonds or only paste. This sort of information, which seems to be of paramount importance in what popularly passes under the name of history, has no part or place in the type of history in which science is interested.

Just exception might be taken to any attempt on the part of a specialist in science to define what constitutes the right sort of history—even though it be history of science. Fortunately, however, some specialists in history have given us a definition of history to which the scientist may give a hearty consent. Traces of this interpretation of history may be found in a number of historical works of the past half century, but it has only recently found extended expression in the writings of Carl Lamprecht and his followers. A good summary of the philosophy of this school of historians was given by Professor Lamprecht in a course of lectures delivered by him in 1904 both in St. Louis and in New York. These lectures have been published in English under the title "What is History?"

For science the most important points in the doctrines of this Leipzig school seem to be these: (1) That history—real history—consists in the portrayal of a series of culture epochs; (2) that the character of these culture epochs is determined by the higher spiritual or psychic attitude of the more gifted of the people, and not by the whims and idiosyncrasies of a line of sovereigns; (3) that the most telling criterion of the psychic attitude of a people at a given epoch is found in the productions of their creative imagination. Hence, if we would understand the nature of the culture of any people at a given epoch, and trace the mechanism of its changes to the next epoch, we must study first of all the products of their creative imagination, *i. e.*, their art, their poetry, their philosophy, and their science. Important, but of secondary importance, are the political, social and economic conditions. In other words, the psychic character of any nation at any epoch is determined by the spiritual attitude of the best people; and this condition is expressed more directly in the works of their creative imagination, and less directly in their political, social and economic conditions.

To sum up this first point, then, we may say that the sort of history needed by science is a portrayal of culture epochs, their character having been determined by a study of the works of the creative imagination of the best people of the time; and hence the importance of the history of science is derived from the fact that science is one of the

productions of the creative imagination, and therefore the study of its history, when properly conducted, should shed immediate light on the problem of determining the nature of the psychic condition of a people at any epoch, *i. e.*, the character of the culture epoch, and of discovering the mechanism of the change from that epoch to the next.

II. But, supposing this to have been accomplished—which has not yet by any means been done—what good will result? Why should we care to gain an insight into the psychic development of a nation?

One immediate consequence of this sort of historical study would be the much-desired humanizing of science; for we should be compelled to recognize the various ways in which science has cooperated with the other phases of human activity in bringing us into our present condition. Still another fruitful consequence would be the gradual extinction of the pernicious notion that scientific conclusions are final—that the *ipse dixit* of science permanently settles all controversy. Other specific benefits might be mentioned: but in this case also all roads lead to Rome, since the central idea of all the reasons for the study of the sort of history that has just been defined is the idea of the analogy or correspondence which exists between the development of a nation and that of each individual of that nation. It is the idea expressed in the *Gliedganzes* of Froebel, in the parallelism between the ontogenetic and the phylogenetic series of Baldwin, etc. It is the idea expressed by Lamprecht when he says: "History in itself is nothing more than applied psychology."[1a] According to this idea we must study the past evolution of science in a people or in a type of civilization in order to understand the evolution of science in the present individuals of that people or of that type of civilization: and conversely, the psychological study of the growth of scientific concepts in the individual sheds light on the scientific growth of the nation.

The meaning and the importance of this idea, not only to teachers of science but to teachers generally, have not yet become fully apparent. Some go so far as to ridicule it. Thus in a very able address on the "Order and Development of Studies suited to Each Stage," Superintendent Wm. E. Chancellor, of Washington, D. C., reaches the following conclusion:[1]

> In this presentation, I have absolutely rejected two familiar theories; that the child must pass through the history of the race, and that he must be prepared directly for participation in the affairs of the modern world. . . . And I have said in terms as unequivocal as they are brief that, to my thinking, as I view the external world of reality and the real world of the soul, we shall find our solution in a genetic psychology that reveals the processes and stages, the functions and the interests, the motives and the ideals, and the principles of the soul as it journeys and sojourns from birth to death.

[1] Report of the Department of Superintendence, 1907, p. 80.

[1a] "What is History?" p. 29.

He does not seem to see that psychology will become more complete and more able to furnish the solution so earnestly desired by all, the more it is studied as applied psychology in history as well as applied psychology in the individual. The two are mutually complementary; by neither method alone can we hope to reach as deep an insight into the meaning of history and the growth of the individual as we can if we use both methods, and continue to work till the results obtained from the two are in substantial accord.

An appreciation of this symbolic relationship, analogy, or correspondence between the whole and the part, the individual and the nation, opens up to the teacher who yearns for the opportunity of carrying on research work a comparatively new, untilled, almost unexplored region for fascinating investigation. The complexity of the problems to be solved, the great value to humanity of the solutions when scientific, and the magnificent opportunities for self-development, for broadening of the personal outlook and for obtaining a clearer understanding of present conditions all offer alluring inducements to every growing man or woman to take part in this new enterprise. By such labor—painstaking, patient, unprejudiced, in a word, scientific—every one may help in gaining for all a better and more adequate interpretation of the past of our civilization and of the present nature of the individual than any hitherto acquired.

In addition, all such study, leading as it inevitably must do to a deeper insight into the realities of the life of mankind and of man, can not fail to inspire the open-minded and earnestly seeking soul with an ever keener appreciation of the majesty, the mystery and the final beauty of humanity. As Lamprecht, after outlining some of the problems of universal history, fitly says:[2]

> On entering the limitless field of universal history, the speaker feels it incumbent upon him to declare that he does it with the greatest diffidence. Whoever thinks along historical lines and has a fair knowledge of some period of universal history, *e. g.*, of the history of a single nation, will be overcome with a feeling of awe at the prodigious many-sidedness and the endless significance of human activities. And, as a result of this feeling, gentle stirrings of the mind are aroused, which take form in sacred admiration of the achievements of mankind; a noble yet dangerous devotion to the grandeur of the human race takes possession of us. . . . We can not enter into problems of universal history, unless we do it with the earnestness of religious feeling, else the standard of the methods which may be used will be completely obsolete and will consequently fail in the application.

This second point may be most fitly summed up in the words of Froebel:[3]

> Every human being who is attentive to his own development may thus recognize and study in himself the history and the development of the race to

[2] "What is History?" p. 185.

[3] "Education of Man," p. 41.

the point it may have reached, or to any fixed point. For this purpose he should view his own life and that of others at all its stages as a continuous whole, developing in accordance with divine laws. Only in this way can man reach an understanding of history, of the history of human development as well as of himself, the history and phenomena, the events of his own development, the history of his own heart, of his own feelings and thoughts; only in this way can he learn to understand others; only in this way can parents hope to understand their child.

III. Having now defined what sort of history is under discussion, we may now turn to ask what we are to understand by science. This term is generally considered to be synonymous with classified or organized knowledge. But if we confine ourselves to this meaning of the word science, and if we think that we are studying the history of science when we study the gradual accretion of classified knowledge, we shall not be able to get from our labors much illumination on the subject of culture epochs; for in the early stages of civilization, in the ruder culture epochs, we find no classified knowledge that would now be recognized as science—no laws of nature, no great abstract principles. Yet there must have been, in those barbaric and primitive times, something that bore the earmarks of science—something which could serve as a means of identifying the nature of the culture epoch from the point of view of science. What was this, and how discover it? Is there any characteristic of scientific work—any typical factor which always appears in a scientific investigation, and whose rudiments may be discovered even in so-called uncultivated epochs and in apparently scienceless eras?

Recently it has been suggested that the scientific status of a nation at any epoch may be determined from a study of the kind of problems over which the people puzzled and the way in which they solved them, *i. e.*, problem-solving furnishes a criterion of culture from the point of view of science. This criterion is evidently capable of universal application, since every nation and every individual of every nation has had to meet and to solve problems. Furthermore, problem-solving always involves, to a greater or less extent, the use of the creative imagination; hence this criterion justifies itself in the light of the definition of history just given, since the kind of history that is needed has to be studied through the expressions of that imagination.

One thing more is necessary in order completely to define our criterion of scientific culture, and that is a statement of the conditions under which problem-solving may be classed as scientific. It is probably not necessary here to more than state those conditions, since their meaning is now so well understood. A problem has been solved scientifically when its solution has stood the test of the most unprejudiced and relentless criticism both from the side of reason and from that of experiment; and also, when the limits within which its solution is valid

have been determined. The importance of this function of the critical faculty in scientific work is too often overlooked; for it is not always so agreeable to remember that criticism is as fundamental a necessity for creative work as is imagination. Since this interplay between the imaginative and the critical faculties is not so well known as the scientific method, we may say that a problem is solved scientifically when its solution has been obtained by the scientific method.

It is important to notice that this definition of science as problem-solving shifts the emphasis in the scientific work from classified knowledge, which is the result of the process, to the process itself, by which the result is obtained. It must also be noted that this definition is more comprehensive than that of classified knowledge, since it may include the operations of a savage in learning to fish and hunt, as well as work by this method in subjects not ordinarily considered parts of science, like classical philology, higher criticism, philosophy and even commerce and politics—not to mention theology.

This third point may now be summarized as follows: The thing whose history is to be studied under the title of history of science is not classified knowledge, the finished product; but it is problem-solving by the scientific method, that active creative process which involves the properly coordinated use of both the imaginative and the critical faculties.

IV. When we attempt to interpret the history of science in the light of the principles just explained, we are bewildered by the complexity and the magnitude of the task. How may any one ever hope to unravel the tangled mass of material that confronts us, or to bring order out of the apparent chaos of problems which have engaged the attention and taxed the energies of mankind. Consider how intricate and how seemingly inexplicable are the problems that overwhelm each individual: how much greater must be the intricacy and the almost hopeless mystery of the problems that vex an entire nation at any epoch! Fortunately, some progress has been made since the time of Hesiod, who wrote: "In the beginning there existed Chaos," the modern view having been expressed by Chamberlain[4] in the words: "No. Chaos has always been at home only in the human mind, never elsewhere." Hence, it is no longer allowable to regard the attempt to find a rational interpretation of the history of science as foolhardy.

A good deal of progress has already been made toward the production of a history of science along the lines here indicated, and a number of practically valuable conclusions have already been reached. For example, the recent discussions of the origin of problems is tending to clarify our notions of how science (problem-solving) originates. This is evidently one of the first phenomena demanding interpretation at the

[4] "Grundlagen des neunzehnten Jahrhunderts," p. 737.

hands of the historian of science. In this matter the historian of science may be of great assistance to the psychologists among whom the discussions are being carried on; since, because of the analogy of the individual and the nation, the origin of a problem in the one may throw light on the similar process in the other.

This may be illustrated by numerous examples. Thus, some psychologists claim that the problems of science grow out of the practical needs of social and economic life. For example, to the primitive man the problem of catching the fish becomes real and definite because of his hunger. In like manner, the problem of the steam engine developed only after there was urgent need of such a machine for mining purposes; and the problem of the electric telegraph was defined by a marked social demand for a quick method of sending messages. The modern inventor finds the impulse to invention in his hope of gaining material reward for a more efficient machine, etc. But while this explanation of the origin of problems may do for those that fall within the realm of applied science, some think that it is not so useful when applied to the problems of pure science, like that of the motions of the solar system, the phenomena of universal gravitation, etc.

In order to account for the origin of this latter type of problem, it has been claimed that the prime factor in the definition of the problems that go to make up science is not to be found in the practical or concrete external situation, but rather in some internal ideal or desire or feeling with which an individual becomes inspired, he knows not how or whence. According to this view, an individual may notice an external phenomenon over and over again without its defining in him a problem. It is only when he notices in the phenomenon two or more factors that do not seem to him to be in harmony—not to accord with some cherished or imagined ideal—that a state of curiosity or of mental tension is induced; and when this condition is reached, he has a problem defined within him, which, if he have any real scientific spirit, does not suffer him to rest until his curiosity is satisfied or his mental tension eased. When this latter state is reached, he is said to have found an "explanation," and the problem is for him solved.

These statements are, of course, but the crudest possible descriptions of but two of the points of view from which the origin of problems has been approached. It will require considerable discussion and study before the whole matter will be cleared up in a tolerably satisfactory manner. But even though the question is far from settled, two important conclusions follow at once from either or both of the points of view just outlined. The first is this: Science is not the source of the progress of civilization. It is rather the faithful handmaid who helps us truly to satisfy the practical needs of society as they become manifest, and to achieve the purposes, ideals, or whatever they are, that

spring up within us somehow to disturb our peace of mind. In other words, scientific problems, and therefore science, originate in either the external situations of concrete experience, or in our ideals, or in both, and hence these latter and not the former are the real source of progress. Thus progress is simply a process of self-realization of society, and science is a powerful tool for the successful carrying on of the process.

The other important conclusion applies to the teaching of science, and it is too patent to need more than statement. It is this: Science in the individual child arises, as it has in society, from either the outer surroundings or the inner purposes of the child. Unless the problem whose partial solution we wish to teach the child spring up within him from either outer or inner necessity, the problem is not his own problem, it is not real to him, and, therefore, its solution is not real to him and so makes no impression. Hence the skill in teaching science is a skill in presenting facts in such a way that the problems whose solutions we wish to teach become the child's own problems. It is thus a skill in causing problems to become defined in the child's mind. The science of the child, like the science of humanity, consists, then, in his own solving of problems that seem to him to arise naturally, either out of his own practical necessities of his own social and economic life, or out of his own purposes, ideals or aspirations that seem to him to have sprung up spontaneously within him. This sort of teaching is quite a different matter from that which generally passes under the name of science teaching, namely, learning the laws and principles of science from a book by memory, with some laboratory and lecture experiments thrown in gratis by way of illustration.

V. So much for the light thrown on present conditions by the study of the origin of scientific problems. But one other example will be added to show the sort of interpretations that may be reached through a study of the way in which various peoples have used their creative imaginations in solving their problems after they had once become defined. For this purpose a problem in applied science will be more illuminating, so we will take this: How was the problem of satisfying the human need of worship solved by the Greeks and by the people of the middle ages? Both expressed their solutions in concrete form in buildings, which still stand as permanent expressions of the workings of their respective creative imaginations.

The Greek temple was a larger and somewhat idealized man's dwelling—a home for deified men and women. It was limited in design to straight lines, since the idea of a curved arch had not yet been achieved in practise. Yet it was a perfect realization of the conception which it was intended to embody—a limited conception, since the idea of deity which makes God to consist of heroic or idealized men and women must

necessarily be cramped and limited. The Greek temple was not intended for public worship of an invisible God, but for the actual residence of their many humanized gods. From this it may appear that their religion was man-made, *i. e.*, that it was no real religion, but only a philosophy; and so we are in a better position to comprehend the classical ancestor worship and the Lares and Penates. When we start from this center we may also get a better insight into the Greek character as a whole.

The middle-age cathedral, on the other hand, bore no resemblance to the dwellings of men. It was a lofty edifice with numerous spires pointing to heaven. It was built for public worship of one God, and was adorned at every point with a richness of tracery and design that would bewilder the observer of to-day were it not so harmonious in all its parts. The conceptions embodied in it are wholly distinct from those ultimated in the Greek temple, showing what a complete and fundamental change in the idea of divinity had come over mankind. The cathedral was not the perfect realization of a limited ideal, but the imperfect realization of an unlimited ideal; and this shows a vast expansion and elevation of the conception of religion—an expansion and elevation that must be ascribed wholly to the christian religion.

Furthermore, the effort to realize these expanded and elevated ideals led to the definition and the solution of numerous practical problems in applied science. The construction of a Greek temple is a simple engineering feat when compared with that of a Gothic cathedral. The solution of these engineering problems lead to the definition of others; and so we see in the middle ages a great development of skill in all sorts of manual arts, carving, metal working, stone cutting, weaving, printing, etc., all before modern science made any pretense of being extant.

Time forbids the following of the argument into detail. There are just two important conclusions that seem to be justified by this comparative study. I will, in closing, state them; and leave the reader to find out if, after further study, he too finds them justified. The first is this: Since Christianity was the source of the ideals that led to the construction of the cathedrals; and since this work and these ideals led to the definition and solution of many problems in applied science; and since the solution of problems in applied science precedes and prepares the way for the definition of problems in pure science; therefore, we may make the hypothesis, subject to further verification, that modern science owes its origin from the side of the imagination to Christianity. Hence the so-called warfare of science and religion is but a sham battle between science and dogmatic theology—between reason and unreason. Modern science is, from this point of view, really the child of Christianity.

The second conclusion that seems justified is no less important for the science teacher. It is this: Since the dawn of modern science was preceded by the solution of a great number of practical problems, which arose from the practical needs and the ideals of the times, and which developed in humanity a great deal of skill in the handling of tools and the mastering of matter, the course of the child in learning science should be similar. Hence, it is unscientific to try to teach modern science to a child that has not been prepared for it by a symbolic middle-age training in the mastery of tools, brute force and concrete matter.

No one can realize more fully than the writer the inadequacy of this discussion of this mighty theme. The same theme has been handled far more completely by Carlyle in the following short paragraphs from his review of the Corn Law Rhymes:

Nay, it appears to us as if in this humble Chant of the Village Patriarch might be traced rudiments of a truly great idea; great though all undeveloped. The Rhapsody of "Enoch Wray" is, in its nature and unconscious tendency, Epic; a whole world lies shadowed in it. What we might call an inarticulate, half-audible Epic! The main figure is a blind aged man; himself a ruin, and encircled with the ruin of a whole Era. Sad and great does that image of a universal Dissolution hover visible as a poetic background. Good old Enoch! He could *do* so much; was so wise, so valiant. No Ilion had he destroyed; yet somewhat he had built up: where the Mill stands noisy by its cataract, making corn into bread for men, it was Enoch that reared it, and made the rude rocks to send it water; where the mountain Torrent now boils in vain, and is mere passing music to the traveler, it was Enoch's cunning that spanned it with that strong Arch, grim, time-defying. Where Enoch's hand or mind has been, Disorder has become Order; Chaos has receded some little handbreadth, had to give up some new handbreadth of his ancient realm. . . .

Rudiments of an Epic, we say; and of the true Epic of our Time,—were the genius but arrived that could sing it! Not "Arms and the Man"; "Tools and the Man," that were now our Epic. What indeed are tools, from the Hammer and Plummet of Enoch Wray to this Pen we now write with, but Arms, wherewith to do battle against UNREASON without or within, and smite in pieces not miserable fellow men, but the Arch-Enemy that makes us all miserable; henceforth the only legitimate battle!

PHYSICS[1]

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IN the upbuilding of all the great and diverse departments of thought, characteristic methods have arisen which the human reason has found best suited to the pursuit of the many phases of truth which it seeks. In the perfection of methods and resourcefulness in applying them, no age has been more fertile than our own. Yet one ever present danger to the orderly and symmetrical development of modern thought, is that those working in different fields for its advancement may lose touch with one another, and the interchange of methods and results so essential to balanced growth be neglected.

If in such a course of lectures as this, each lecturer coming from a neighboring or distant field succeeds in showing the nature of the evidence he has been taught to consider, his methods of weighing it and some of his results, the university will be the gainer in increased knowledge, in broadened sympathies and in a deeper realization of the wholeness of truth.

It is doubtful if our understanding of the unity of external nature can ever be illuminated by the lamp of any one of the natural sciences. The division of nature into separate departments of study has been an intellectual necessity caused by the greatness of the task.

The easiest cleavage would separate the animate from the inanimate, the biological from the physical sciences. This cleft, the first to form, will be the last to close; for to define the precise relations of life to matter is now one of the most intricate and difficult problems in the whole range of human endeavor. Who will fundamentally answer the question, how does a seed become a tree?

The phenomena of inanimate matter are involved and complicated in the extreme, but those of living matter are even harder to understand. The outward or objective manifestations of life are of a material or physical character, and the purpose of the biologist is to apply to them the principles of physics and chemistry as far as these will carry him, and in many directions they have already carried him far. When, however, we consider the subjective phenomena of life, or consciousness, the question seems to me a metaphysical one and we are without assurance that physics and chemistry can lead us beyond the boundaries

[1] A lecture delivered at Columbia University in the series on science, philosophy and art, as the opening lecture in the natural science group, October 23, 1907.

of it. Indeed, just where physics and chemistry leave off, I feel a real and deeper problem begins. If so, the question lies at present beyond the reach of natural science which biologist and physicist alike interpret as the science of matter and energy.

In what follows I shall try to review very briefly the principal ideas upon which modern physics rests and shall say something about where we think we have arrived in our search for knowledge. I need scarcely remind you that in the natural sciences as in more practical affairs, *how* we have arrived is as important as *where* we have arrived. I shall therefore spend some time in presenting detached fragments of the experimental evidence and inferences upon which certain conclusions are based, hoping in this way to illustrate some of the constructive methods of reasoning employed in research.

The ideas which underlie all our thinking are space, time and inertia or mass. With space and time as a background, the physicist must pursue inertia and everything related to it, along every conceivable path. In this pursuit he comes upon four ultimate though related conceptions: matter, ether, electricity and energy.

The historical development of these conceptions can not even be sketched in such a lecture as this, but it should be remembered an important part of our present knowledge of matter, and nearly all that we know of the ether and electricity has been gained not immediately, but by inference. In so many cases we see or know directly only the first and last link of a chain of events and must search by indirect means for the mechanism lying between.

At bottom, I suppose, the ether, electricity, force, energy, molecule, atom, electron, are but the symbols of our groping thoughts, created by an inborn necessity of the human mind which strives to make all things reasonable. In thus reasoning from things seen and tangible, to things unseen and intangible, the resources of mathematical analysis are applied to the mental images of the investigator, images often suggested to him by his knowledge of the behavior of material bodies. This process leads first to a working hypothesis, which is then tested in all its conceivable consequences, and any phenomena not already known which it requires for its fulfilment, are sought in the laboratory. By this slow advance a working hypothesis which has satisfied all the demands put upon it gradually becomes a theory which steadily gains in authority as more and more new lines of evidence converge upon it and confirm it.

If we now consider more closely the nature of the conceptions, matter, ether, electricity and energy, we shall later find that matter, ether and electricity possess some attributes in common, and if we take careful heed to what we shall understand by the word, we may call them substances. Energy appears as the measure of their possible interactions.

Taking energy first: All the numberless changes we see taking place in the universe are, we think, manifestations of the interactions among matter, ether and electricity. With every changing aspect of nature, energy is passing from body to body and undergoing incessant transformations, but its amount is always measurable by the work it may accomplish when harnessed.

Our knowledge of the uncreatable and indestructible character of energy has given us a universal test which we may freely apply to all phenomena to prove our knowledge of them. For when the required energy relations are not satisfied by our explanations, it means we have not got to the bottom of the case, but must strike deeper in to realize the whole of the concealed mechanism.

Charmed by the simplicity and sweep of the law of the conservation of energy, a small school of physicists, who have mostly entered in by the door of physical chemistry, have frankly set energy before inertia and have endeavored to deduce matter and all else from it. This can of course be done, for physics has become a body of thought so closely knit together that all things in it are somehow related. Seen broadly, however, the new method has few obvious advantages over the historic procedure and not a few evident defects.

Matter has two indisputable hallmarks, two properties in the possession of which all the infinitely varied forms of matter unite, inertia and weight. By inertia we mean that active resistance shown by every piece of matter to any effort to change its motion; while the mutual attraction between all material bodies, according to which all matter strives to collect itself into one huge compact lump, we call gravitation. The gravitational pull of the earth upon a portion of matter is its weight. If we find anything in the world, however strange, which possesses both inertia and weight, we may call it matter without further examination.

The ether which surrounds and encloses all our universe we came first to know as the bearer of waves of light and heat. Ever since that time we have known it to possess inertia; for no medium devoid of inertia can carry forward a wave motion.

Thus the ether has one of the hallmarks of matter. Has it also weight? This we can not hope to know until we find some way as yet undiscovered to alter the natural distribution of ether between two portions of space. Here it should be remembered that the weight of gases was first proved after the invention of the air pump and barometer. But, alas! how shall we go about building an ether pump when all material walls seem more porous to the ether than the coarsest sieve is to air? And worse, the ether appears to be incompressible. The question of weight is thus at present in abeyance and we leave it.

Of the properties of electricity alone, it is still difficult to speak. The subject is easiest approached from the relations of electricity to

ether on the one hand and the relations of electricity to matter on the other. It is in this last and more complicated phase of our subject that the most brilliant advances have recently been made.

To state the case between electricity and ether, we must begin with Faraday and some of the mental images he formed of the connection between them, which have proved at once the most simple and useful aids to thought to be found in the whole history of physics. Faraday realized as well, perhaps, as we do to-day that electricity could no more be made outright than could matter. The utmost which could be done was to separate positive and negative electricity. If, therefore, any one exhibited a positive charge, there was somewhere in the universe an equal negative charge, to which it was drawn by invisible means across the intervening space.

Faraday maintained the forces of attraction were due to some kind of strain in the ether lying between. To picture the more vividly to himself and to others, the character of the stresses in this medium transmitting the force which one charge exerts upon another, he supposed contractile filaments called lines of force to traverse the ether between the charges. To make the case more definite he gave direction to these lines, assuming that they originated on the positive charge and terminated on an equal negative charge near-by, or far away, according to circumstances.

The motions of electric charges when free to move, and the distribution of stresses in the ether round-about, show that all happens as if each line of force were pulling like a stretched elastic thread to shorten itself and draw the charges together, and at the same time unlike any elastic thread we know, it was repelling or pushing sidewise at the other force lines near it.

If a charge of positive electricity be given to a metal sphere, and the negative charge from which it has been separated be dissipated to remote bodies or be carried so far away that its position is no longer of any immediate importance, lines of force will start from the spherical surface of the conductor in all outward directions, and will be precisely radial. As many lines will leave from any one half of the sphere as from another. This equal radial arrangement of the lines of force is produced by the sidewise shoving of each line of force upon its neighbors until the stresses in the ether at the bounding surface of the metal are equal on all sides.

If now the metal sphere with its charge be put in steady motion, it will carry its lines of force along with it, and if the motion be not too swift, all the lines of force will continue radial. But with this motion of the lines of electric force through the ether, a wholly new and additional ethereal force appears—a magnetic force which did not exist when the charge was at rest. This magnetic force is always at right angles both to the lines of electric force and to the direction of their

motion, thus encircling the moving charge. The planes of these circles are perpendicular to the straight path along which the charge is traveling.

As long as the motion and charge remain uniform there will be no change whatever in this magnetic force except that it keeps abreast of the sphere as do the moving lines of electric force on which it depends. As soon as the motion ceases, the magnetic force disappears and soon all is as it was before the motion began. But while the sphere is starting or stopping, before it has reached its steady motion or while it is coming to rest, the electric and magnetic forces are undergoing readjustment and this disturbance spreads outward through the ether with a speed precisely equal to the speed of light. Nor is this a chance agreement, for we now know that light consists of nothing more than very rapidly and periodically changing electro-magnetic forces traveling out through the ether from a particular source of electric disturbance, called a luminous body. The ethereal phenomena we have noted around a moving charge faithfully repeat themselves about a wire carrying an electric current and it was here that Faraday found them.

To the mental images of Faraday—these lines of force which helped him to grapple with the unseen, to form working hypotheses, to experiment: to these Maxwell applied the powerful resources of mathematical analysis and reared the splendid structure of the electro-magnetic theory. Now that the work is done we may let fall the scaffolding which Faraday's vivid imagination supplied, but we could not earlier have done without it. Here we have the whole chain, mental image, hypothesis, experiment, theory.

As we now take up what we believe to be the relations of electricity to matter, we come in places upon slippery ground and the bases of our faith rest on recent foundations.

At the outset we encounter one striking difference between electricity and matter. Every free charge exerts a force upon every other charge in the universe, just as every particle of matter exerts a force on every other particle of matter however distant. But with matter the particles are invariably urged toward each other while electric charges may be either drawn together or forced apart, depending on the kinds of charges. We have both positive and negative electricity, but only one kind of matter.

Just how these two kinds of electricity are different we know little beyond the invariable law that positive attracts negative and repels positive. In some ways positive and negative electricity resemble right- and left-handed things. If the same number of right- and left-handed turns be given to a screw, one hand will precisely undo the work of the other. If the right and left hands be brought together they fit part for part, but two right gloves are a poor pair. On the contrary, there

is no right and left to gravitation. Two pieces of matter always fit in the gravitational sense.

The bald statements of the laws of gravitation and electric force bear a strong resemblance to each other. The laws tell us how the forces *vary,* but reveal no hint of the machinery by which they *act.*

Gravitation was the first force man encountered and it is still the one he knows least about, for we have got no farther than where Newton left it two and a half centuries ago. We have some inkling of the possible machinery by which one electric charge acts upon another at a distance and we feel nearly as sure that the push or pull is carried by the ether as that the pull of a horse on a cart is through the traces which bind him to it. With gravitation the case is very different, for we have not as yet the slightest valid conception of *how* the pull of one mass upon another is conducted across the intervening space, nor *what* conducts it. We can get no farther until the speed with which gravitational disturbances travel has been measured, and no one at present seems to know how to go about making such an experiment.

One further difference between gravitation and electric force. The force of attraction or repulsion between two charges of electricity is diminished by replacing the free ether between them with any material medium, but the force of gravitation between two bodies remains constant as long as the distance remains constant, and intervening masses are powerless to shield or to alter it. Hence we can not yet attribute the gravitation of matter to any electricity which may be contained in it, nor prove the ether to be the medium through which the force acts.

Gravitation is still unconnected, unattached to anything else in nature; as independent as Mr. Kipling's "cat that walked by himself, and all places were alike to him." It is still the stumbling block to the physicist which it has been these many years. How can he explain a universe when he is unable to give a reasonable account of the cement which holds it together?

Of the intimate association of electricity with matter we have learned much from careful study of the processes of electric conduction in solutions and gases.

When a simple chemical compound (and it should here be borne in mind that the molecule of a compound is built up of atoms of at least two different kinds)—when a simple chemical compound, hydrochloric acid for example, is dissolved in water and an electric current is passed through the solution, the products hydrogen and chlorine of the decomposed acid appear in definite proportions at the points where the current enters and leaves the liquid—the chlorine where the current enters, the hydrogen where it leaves. We know this current to consist of processions of single charged atoms, a disorderly march, perhaps, with a crowd of bystanders obstructing the way, but the movement is always forward, each constituent of the broken molecule carrying a definite

electric charge. These processions are always double, the atomic carriers of the positive charge moving in one direction, those carrying the negative charge in the other. The same quantity of positive electricity is carried by one procession, as negative electricity by the other. We have not only measured the charge carried by a single atom, but the average speed with which the atoms traverse the solution. It has been found, further, that atoms of the different chemical elements having the same mating value, technically called valence, always carry the same unvarying charge, whether the atoms themselves be light or heavy. These charged atoms, in some cases atom groups, are spoken of as *ions.*

Such electrolytic experiments as these have led to two surprising results. First: no electric charge smaller than that carried by an atom of the hydrogen valence has yet been found. Second: all other small charges are exact multiples of this value.

We have long been familiar with the idea of atoms of matter, but here for the first time we come across something which looks very like an atom, or natural unit, of electricity. The justification for calling it an atom of electricity is like the argument for the atom of matter. Moreover, we know some eighty different kinds of material atoms, but only two kinds of electric atoms, a positive and a negative. Thus the electric atom of the two has the greater claim to simplicity. When we speak of an electric atom disregarding for the time the matter associated with it, we call it, not an *ion,* but an *electron.* Evidence will later be given suggesting ways by which we may wrench a negative electron wholly free from matter, and experiment with it in its detached and pure state.

We are now in a position to consider the rôle electric forces play in holding atoms together within a compound molecule, for, from the foregoing, it appears when a molecule is broken in two, the fragments are always found equally and oppositely charged, and they doubtless held these charges within the molecule. But the distance separating the two parts was then so small that all the lines of force from the positive charge ended at once on the equal negative charge, and no force lines strayed beyond the molecular boundary. Hence no evidence of an electrical charge could be found in the ether outside the molecule. It seems probable, therefore, that the electric force between the atoms of matter in the molecule supplies the chemist with the cement he has long called *chemical affinity.*

The ratio of the electric charge to the mass of the particle on which it rides (in our processions) has come to be one of the most important quantities in physics. As we know both the quantity of matter and quantity of electricity transferred by a given electric current, we can express this ratio for each chemical element. Hydrogen gives the largest ratio found in solutions.

Systematic study of the conduction of electricity in gases is of more

recent origin, but the knowledge gained from it not only confirms the ideas formed to explain conduction in solutions, but has very widely extended and simplified them. The chief difference between electric conduction in solutions and conduction in gases arises from the large number of broken molecules or ions always present in solutions. These require only the presence of an electromotive force to start them marching, but a gas, in its natural or non-conducting state, contains very few ions, not enough to support even a very small current, and for this reason gases are insulators.

In gases, however, there are many ways of making ions, X-rays, radium rays, rays of ultra-violet light on metals, combustion in flames, white-hot bodies of every sort will do it. But there is one method which depends on the violent collisions of ions with molecules which is so objective in its form I can not forbear attempting to describe it. It is also the method which leads us to cathode rays and much more.

Imagine, then, a glass tube into each end of which a conducting rod carrying a small metal disc is sealed. These rods may at will be connected to the terminals of a battery. If while the tube is filled with a gas, in its non-conducting state, the battery be applied, the very few ions always present are set in motion, but the too frequent collisions in the swarm of neutral molecules which obstruct the way prevent the moving ions from attaining more than moderate speeds.

By connecting the tube to an air pump as many as we like of the interfering molecules may be removed. As more and more gas is drawn out of the tube, the moving ions encounter fewer and fewer collisions and in consequence attain higher and higher speeds, as small shot might fall through a gradually dispersing swarm of bees poised in midair. The longer the pumping is kept up the greater the maximum speed of the ions becomes and the more violent are the collisions which do occur. When nearly all of the gas has been drawn out of the tube, a stage is reached where the encounters between flying ion and indifferent molecule become so violent that molecules are shattered and new ions produced, which in their turn work more destruction.

When this stage is reached, the gas is a good conductor, but if the pumping be carried too far, a second stage appears in which the encounters are too few to make enough new ions to support the current, and the gas finally ceases to conduct systematically. It is near the end of the conducting stage that the much-discussed cathode rays appear. They depart from the cathode or metal disc in the end of the tube connected to the negative side of the battery.

The extraordinary resourcefulness, shown by the leading workers in this field of recent enquiry, in untangling the complex snarl of phenomena presented, marks a very great achievement. So inspiring from the human side as well as the physical has been this unequal contest of man with nature, of mind struggling against disorder, and so bravely

done, that I ask your indulgence while I try for a few minutes, fragmentarily, to describe one or two fundamental experiments.

Cathode rays are invisible, but many substances—fortunately glass is of the number—shine with a bright phosphorescent light when placed in the path of the rays. By this means it was early discovered that cathode rays travel in straight lines which always leave the cathode making right angles with the metal surface from which they depart. It is possible, therefore, to make the cathode concave or saucer-shaped and thus bring the rays to a focus at some point in the tube. If cathode rays are thus focussed upon the blades of a very delicate paddle wheel which rotates easily upon an axis, the wheel is set revolving as if struck by a stream of moving matter.

The rays are found to possess an unusual power of penetrating matter impervious to light. They will even traverse a considerable thickness of aluminum. A comparison of the absorbing powers of different materials for cathode rays shows absorption to be roughly proportional to the density of the substance.

There is a field of magnetic force about a beam of these rays and this added to the transfer of electricity along the path gives to the cathode stream the distinguishing marks of an electric current in a wire or a procession of electrically charged bodies. If a magnet be brought near the tube the cathode stream is deflected from its direct course. This deflection by the magnet shows three things: first, cathode rays are not of the nature of light rays, the path of which a magnet is powerless to change. Second, the curved path which the stream follows again shows the stream to possess inertia. Third, the side to which the rays are deflected indicates a stream of negative electricity.

Strongly electrified bodies brought near the tube also deflect the rays. It is possible to determine the speed and the ratio of charge to the mass of the cathode particle, by measurements of the curvature of the path due to the combined magnetic and electrostatic deflections. Speeds as high as one tenth the velocity of light or 100,000 times the speed of a modern rifle bullet have thus been observed. The ratio of charge to mass comes out nearly a thousand times that found for the hydrogen atom by electrolysis. If the charge on the cathode particle is no larger than that on the hydrogen atom, which was called an atom of electricity, then the inertia or mass of these particles is only one one-thousandth part of the mass of hydrogen atoms.

The nature of cathode rays was thus determined, but at this stage it was all important to catch a known number of these missiles and measure the electric charge each carried. As the estimated size of these minute bodies is less than one ten-million-millionths of an inch, direct counting would be both slow and difficult, yet by one of the most ingenious experiments ever performed, Professor J. J. Thomson did it, indirectly.

To bring the essential features of this remarkable experiment before you, I must begin some way off by reminding you of several things you already know. For instance, the quantity of water vapor which a given volume of air at ordinary pressures can hold without depositing it as a mist or rain increases with the temperature. If air enclosed in a vessel is allowed to expand suddenly its temperature falls. If the air were initially saturated with water vapor, after the expansion some of the vapor will go into mist or rain, provided any nuclei are present upon which the excess vapor can condense. In the ordinary fog or shower the dust particles always present in the open air act as nuclei for the formation of drops. Small free charges of electricity or ions serve the same purpose and the negative ions are more effective condensers than the positive, hence they come down first.

In a complicated vessel, which need not be described, Professor Thomson admitted dust-free air saturated with water vapor. This mixture was allowed to expand several times to make sure of freeing it from accidental dust or ions which might be present. The former pressure was then restored and the gas ionized by admitting X-rays through the thin aluminum lid of the gas chamber. The next expansion, chosen sufficient in amount to cause condensation on the negative but not on the positive ions, caused a copious cloud of mist which gradually settled by its own weight to the bottom of the vessel. The top of the cloud as it fell was sharply defined, and its rate of descent could be measured.

Sir George Stokes many years before had calculated the rate of fall of small spherical bodies through air, and one needed to know only the density of a small sphere and its rate of fall to compute its size. The approximate volume of the individual drops could thus be found. The quantity of water in the whole shower could also be easily determined, hence the number of drops, equal to the number of negative ions upon which they might form, could be calculated.

In another way Professor Thomson could measure the total quantity of free negative electricity present in the chamber when the fog was precipitated. He had thus the number of negative ions and the sum of their charges, and therefore the charge each carried.

The charge Professor Thomson found as the result of his brilliant experiment was the atom of electricity over again. After this it was impossible to escape the conclusion that the bodies flying in the cathode stream were masses no greater than the one one-thousandth part of the hydrogen atom. Thus matter, or electricity, or something exists, which measured by inertia is a thousand times smaller than the lightest known atom of matter. Furthermore, the kind of gas in which the cathode discharge took place had no effect upon either the charge or the mass of the particles, which bear no observable earmarks to reveal the kind

of matter out of which they come. Whatever their source, they are always the same.

So far as we now know, the cathode particle or negative electron is a minute portion of pure negative electricity, wholly free from matter. An atom of electricity, and nothing more. Its small inertia can be wholly explained to be of the kind electric charges borrow from the ether which surrounds them.

When electrons driven at high speeds down the cathode stream are suddenly stopped by striking a target of dense matter like platinum, the point where the target is struck becomes a source of X-rays. We have already seen that a moving electric charge when brought to rest sends out a pulse of electro-magnetic disturbance in the surrounding ether, and the greater the suddenness with which the motion is arrested, the sharper and more abrupt is the shock to the ether.

In one sense the principal difference between X-rays and the yellow light from a sodium flame is analogous to the difference between the air disturbances caused by an irregular jumble of sharp thin reports of small percussion caps, and the droning of a heavy organ pipe. One is a tangle of single shocks, the other a steady wave motion. Thus regarded, nearly all the remarkable properties of X-rays find a reasonable and easy explanation.

Turning now to the positive terminal of the tube: Under suitable conditions of experiment it is possible to get a stream of particles from it. Named as children are before their natures are in the least understood, these rays were called *canal rays*. Like cathode rays, they consist of flying missiles, but carry positive instead of negative charges. Compared with cathode rays, their speed is very moderate and the ratio of charge to mass is of the same order as that for the lighter atoms in conduction through solutions. This ratio varies somewhat with the kind of gas in the tube. Thus canal rays are probably a stream of material atoms which have lost one or more negative electrons.

All efforts to obtain a charge of positive electricity free from matter —a veritable positive electron—have thus far failed.

The extreme complexity of the material atom is strikingly shown by the light from incandescent gases and vapors. When examined by the spectroscope the single element iron exhibits hundreds of definitely placed bright lines in the visible spectrum alone, which means the iron atom must be capable of vibrating in hundreds of different periods. No single atom need be vibrating in all these ways at the same instant, but if all iron atoms are alike, and we have every reason to believe they are, whether shining on earth or in the stars, then every atom of iron must be capable of swinging or bounding, revolving or shuddering, or doing something in all these ways.

Before the evidence of the spectroscope the older idea of the atom as a simple structureless body falls to the ground. The complexity of

a grand piano seems simple in comparison with the iron atom. But spectroscopic evidence does not end here, but indicates *what* it is in the atom which does something and *how* it does it.

Ten years ago Professor Zeeman placed a sodium flame between the poles of a powerful electro-magnet and examined its light by the spectroscope. He observed the most striking and peculiar effects of the magnetic force on the character of the light. The time is too far gone to permit a description of what the effects were, but the light sent out by the flame showed exactly the characteristics which magnetic force would produce, provided the light came from atoms inside which minute electric charges were rapidly revolving. It was even possible to compute the ratio of charge to mass for these revolving mites. The ratio revealed was that previously obtained for the cathode particle.

Hence the mechanism which enables the material atom to emit light may be the same electron we met flying through the vacuum tube, now revolving in an orbit about the atom center as a planet revolves about the sun. Thus the chief difference between the atoms of one chemical element and those of another, may lie in the number and arrangement of electrons in a revolving system.

It had long been known that hints about the internal fabric of the atom would be most effectively sought with the spectroscope, but we have here gained at a single bound the most amazing insight into a most complex system. Here also we meet another of those astonishing previsions of Faraday. He tried Zeeman's experiment over fifty years ago, but was balked in his quest by the inadequacy of the instrumental equipment of his day.

The quite recent discovery of the wholly new and unsuspected property of radio-activity in a group of heavy elements has done much to confirm the views already expressed of the connection between electricity and matter, and much more, for radio-active phenomena suggest for the first time that some kinds of matter are not only unstable, but mutable.

Taking radium as the most highly developed example of its class, we find it, with the help of its numerous progeny, sending out three distinct types of rays, which for convenience of classification have been called α-, β- and γ-rays.

α-rays closely resemble canal rays. They carry positive electric charges and possess a mass or inertia comparable with that of the helium or hydrogen atom.

β-rays appear identical with cathode rays. They consist of negative electrons hurled out at speeds as great as nine tenths the velocity of light.

γ-rays are of the nature of X-rays—a purely ethereal phenomenon. All these rays penetrate matter to varying depths, and absorption varies with density as in cathode rays.

α-, β- and γ-rays all have the power of wrenching electrons free from substances which absorb them. By this power to ionize gases a wholly new method of chemical analysis has sprung up—the method of analyzing by the electroscope. So marvelously delicate is this new radio-analysis that one part of radium in one hundred-million-million parts of uranium can not escape detection. The electrometer test for differentiating the various radio-active substances is the time required for the fresh product gained by chemical manipulation to lose half its ionizing power. This important characteristic of each substance is disparagingly called its *rate of decay.*

By the aid of the new analysis, Rutherford and others have found that radium is slowly disintegrating into radium emanation, which in turn changes into a distinct substance called radium A, and so on by successive steps down the alphabet to radium F, which is possibly a parent of lead. Helium appears also as a by-product of radium disintegration. From radium downward each of the seven substances has a characteristic rate of decay ranging from 1,300 years for radium, to three minutes for radium A. Radium emanation is a gas which liquefies at — 150° C. Some of the later products seem to be solids.

Is it not amazing that any of the properties of these six derivative products should be known at all, when never yet has one of them been seen, nor weighed, nor caught for direct examination?

Not only has radium offspring down to the sixth and seventh generation, but it apparently has ancestors as well. It is only a link in a genealogical chain. The probable discovery of radium's immediate parent was published less than a month ago by Boltwood. Uranium is thought a remoter ancestor, possibly a great-grandparent.

Accompanying the atomic disintegration of radio-active substances, large quantities of heat are evolved showing vast stores of energy hitherto unknown inside the atom.

The most reasonable explanation yet offered of the observed radio-active phenomena indicates that the complex system of electrons revolving at enormous speeds within the atom gradually loses energy until the configuration becomes unstable. A sudden readjustment takes place—a kind of internal explosion by which electrons or α particles, or both, are hurled out. The atomic structure thus relieved starts life as a new substance with a lower atomic weight. Later the new substance for a like reason again becomes unstable, another explosion occurs, and an atom of yet another substance is born.

If this interpretation of the evidence be accepted a conclusion of vast importance may be drawn. We have, we can not say going on before our eyes, but we may say in a sense going on under our hands, a slow evolution or transmutation of matter. This conclusion is not accepted as yet without reserve, for it strikes too deep at one of the assumptions of our older knowledge. Material atoms have long been

thought of as immutably fixed for all time, but so were animal and plant species before Darwin. The growing evidence for this larger view of matter, though recent, is already too strong to be longer ignored. The burden of proof is gradualy shifting, and to Alice's question, "Why?" comes back the equally pertinent "Why not?" of the March Hare.

To gather a little together: The electron has but a thousandth part of the inertia of the lightest known material atom, and this inertia it doubtless borrows from the kindly ether and does not hold in its own right. Its behavior is that of an atom of negative electricity pure and simple. Its form is spherical and not spheroidal. Its size is probably less than one ten-million-millionths of an inch. When revolving briskly enough in an orbit within the atom it gives us colored light of highest purity. When violently jostling irregularly about it gives us white light. Without it all light would be impossible.

We believe we have found electricity free from matter, but never yet matter free from electricity. Finally comes the suggestion that matter no less than life may be undergoing a slow but endless evolution.

Some of these things and many others have led physicists to suspect that if all electricity were removed from matter nothing would be left, that the material atom is an electrical structure and nothing more.

There are, however, many stubborn questions to which answers must somehow be found before the so-called electron theory of matter can be accepted unreservedly. As it stands it is at once a most brilliant and promising hypothesis, but has not yet reached the full stature of a theory.

Should it hold good, the material atom with its revolving electrons becomes the epitome of the universe. The architecture of the solar system and of the atom, the very great and the very small, reveals the same marvelous plan, the same exquisite workmanship. The conservation of energy becomes an ethereal law and the ether the abiding place of the universal store of energy.

To end as we began, we have matter and electricity which some day may be one, and ether and energy. Of these we hope some time to build in theory a reasonable world to match the one we now so little understand.

When all the interrelations among matter, ether, electricity are separated out and quantitatively expressed, we believe our work will be complete.

Such, then, is the confession of faith, the very far-distant hope of the modern physicist.

THE RESPIRATION OF AN INLAND LAKE[1]

By Professor E. A. BIRGE
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AN inland lake has often been compared to a living being, and this has always seemed to me one of the happiest of the attempts to find resemblances between animate and inanimate objects. Unlike many such comparisons, which turn on a single point of resemblance and whose fitness disappears as soon as the objects are viewed from a different position, the appropriateness of this increases rather than diminishes as our knowledge both of lakes and of living beings is enlarged.

The lake, like the organism, has its birth and its periods of growth, maturity, old age and death; and this fact is an obvious one, for of all the larger features of the landscape, the lake is the youngest and the most temporary. Its birth lies in the recent past, and in no very long space of time its existence must come to an end. In any lake district, lakes may be found in all stages of maturity and decay, and many dead lakes will be seen—places where lakes once existed which are now extinct. Lakes show not only the cycle of individual existence, but also the rhythm of seasonal activity. The activity of the lake in summer, both physical and vital, contrasts sharply with its torpidity in winter. And the lake resembles the organism not only in its annual recurrence of activity. The comparison may be pushed farther and extended to the minor fluctuations of the vigor of vital manifestations which characterize lake and organism alike.

In all these points, and in many others, the lake resembles a living being; but in no respect does it resemble an organism more closely than in the topic on which I am going to speak to you, namely, its respiration. In this comparison, the resemblance is rather in processes and operations than in form. The lake is morphologically a very simple creature, resembling rather a gigantic amœba than a more highly organized being. Perhaps it would be better to compare the lake, for the purpose of this subject, not with the organism as a whole, but with the special respiratory substance of the animal—the blood.

Like the blood of the higher animals, the lake consists of an unorganized fluid—the plasma of the blood and the water of the lake—and of numerous organized and actively living parts—cells in the case

[1] Address of the President at the Thirty-sixth Annual Meeting of the American Fisheries Society, Erie, Pa., July 23–25, 1907.

of the blood, and the plants and animals in the lake. As is the case in the animal, the respiratory gases are absorbed and transmitted to the living structures by means of the unorganized fluid. It is my purpose to trace in outline the history of these processes and their result upon the activity of the lake.

The respiration of the lake, like that of the higher animal, may be divided into external and internal respiration. By the former we understand the adsorption of certain gases from the air and the return of other gases to it, as well as the processes by which this exchange is effected. We include in it also the methods by which the gases are distributed in the lake and conveyed to and from the surface of the water, which takes them from the atmosphere and gives them back to it. By internal respiration we mean the gaseous exchanges which take place in the lake itself, between its various organisms and the water surrounding them. With these exchanges come the chemical processes by which the character of the gases is altered or new gases manufactured, in the course of the vital activities of the inhabitants of the lake.

The external respiration of the lake closely resembles that of the organism. The lake absorbs oxygen, carbon dioxide and nitrogen from the atmosphere, and returns to it nitrogen, carbon dioxide and sometimes other gases. The nitrogen absorbed by the lake, like that taken in by an animal, has very little or nothing to do with the vital processes. In autumn, as the lake cools, larger amounts of nitrogen are absorbed, according to the general law of absorption of gases. As the lake warms during the summer season, the capacity for holding gases in absorption becomes smaller and some of the nitrogen is lost. This process is a purely physical one and has apparently no influence on the life of any of the organisms whose home is in the water.

The relation of the oxygen to life is, however, far different, and the processes of external respiration are of prime importance to the living beings of the lake. Speaking roughly, and in terms of our comparison, we may say that an inland lake is an organism which takes one full inspiration in the fall, and another, less complete, in the early spring; that during the winter it does not breathe at all and during the summer has only a very shallow and imperfect respiration. As the lake cools in the fall the temperature becomes uniform from top to bottom at a date which will vary from late September to late November or early December, according to the area and the depth of the lake and the consequent temperature of the bottom water, the volume of water to be cooled, and the vigor of the cooling processes. When the temperature has thus become uniform, the water of the lake is readily moved throughout its entire depth by the wind. It is turned over and all parts of it are brought into contact with the atmosphere. As a result,

inland lakes, even those whose depth is two hundred feet or more, become almost, or quite, saturated with oxygen at a temperature but little above the freezing point. This quantity amounts to about 10 c.c. per liter, or about 1 per cent. by volume; nearly twice as much as the water will hold at the highest summer temperature. In this condition as regards oxygen the lake goes into winter quarters, becomes covered with a sheet of ice in our latitudes, and is, therefore, shut off until spring from all further direct connection with the atmosphere. During this period the stock of oxygen is used up to some extent, especially in the water adjacent to the bottom. But as the vital processes of both plants and animals, and also those connected with decay, go on slowly at the low temperature of the water in winter, the amount of oxygen thus consumed is comparatively small, and most lakes contain an abundance for all forms of life at all depths, except perhaps in the strata very close to the bottom. This statement, though generally true, will not hold universally. In some ponds which are shallow and contain a large amount both of living organisms and of decomposing matter, the oxygen beneath the ice may become wholly used up. We all know of lakes where, if a hole is cut through the ice in late winter, the fish will crowd to it for air so eagerly and in such numbers as to be forced out on the ice. There are on record cases where an unusual exhaustion of the oxygen below the ice of a lake has caused the death of most of the fish. Such cases, however, are not common, and in the great majority of lakes the consumption of oxygen in winter does not go far enough to affect unfavorably their living inhabitants.

Associated with this partial exhaustion of oxygen, there is an increase during winter of the amount of carbon dioxide—the main gaseous product of respiration. This is not present in any observable quantity in the lake at the time of freezing, but it increases during the winter and the quantity at the bottom may become very considerable. The amount will be, in general, proportional to the amount of oxygen used up. In the spring, when the ice has melted, the water of the lake is once more uniform in temperature. It is put into motion once more by the wind and all parts of the water are brought into contact with the air. The carbon dioxide, which has been accumulating during the winter, is discharged or used by plants and the lake again becomes nearly saturated with oxygen. But, as the temperature in spring is higher than in the autumn, the amount of oxygen taken in is less, and since the temperature of the water continues to rise, the stock of oxygen is being diminished from this cause quite independently of any use made of the gas by the organisms of the lake.

The period of full oxygen saturation in the spring is a brief one in our climate. The season advances very rapidly and the surface water soon acquires a higher temperature than that at the bottom. This

warmed water is, of course, lighter than the cooler water below and tends to float upon it. The difference in density thus caused makes it increasingly difficult for the wind to create and maintain a complete circulation of the water. For a time the action of the wind may continue to mix each successive stratum of water with that below it, the mixture extending to the bottom of the lake. But this action is a very different thing from a complete overturning of the water; and while it results in raising the temperature of the lower water, it does not carry freely oxygen to the bottom. Thus, when the surface becomes decidedly warmer than the water below it, the bottom water, though it continues to warm, is withdrawn from direct contact with the air and is therefore at a disadvantage in the matter of gaining a new supply of oxygen.

As the season advances this stratification of water dependent on temperature becomes accentuated, and the lake becomes separated into two parts: an upper warm stratum of nearly uniform temperature, beneath which lies the cold water consisting of a transition layer—the *thermocline*—in which the temperature is rapidly falling, and below this the mass of the cold water whose temperature ordinarily falls rather slowly with the depth until the bottom of the lake is reached. The thickness of the upper layer varies with the size of the lake, from ten to twelve feet to thirty or forty feet. It is present as a definite and permanent layer at a date varying with the area of the lake from late April to the middle of July. It increases in thickness after the cooling of the lake begins, but does not change much before that process commences.

This upper layer is subject to the direct action of the wind, is kept in circulation, and may be saturated with oxygen, or nearly so, but the only new supply of oxygen which the lower water can gain must come to it indirectly from the upper stratum. This condition of permanent stratification of the water comes on at the time when the life of the lake and its consequent need of oxygen are rising to the maximum, with the increasing warmth of summer and the development of life. The consumption of oxygen for the purposes of decomposition is also at a maximum. The separation of the lower water from the atmosphere in summer by a thick layer of warm water is therefore a much more serious thing than the separation of the water from the air in winter by ice. In winter the demand for oxygen is at a minimum and the stock contained in the water is at a maximum. In summer both of these conditions are exactly reversed. It is therefore necessary for us to inquire as to the means which the lake has for absorbing oxygen from the air and its means of transporting the gas from the surface to the place where it is to be used, and to note the efficiency of these processes as compared with the call for oxygen in the summer life of the lake.

The absorption and distribution of oxygen constitute one of the fundamental problems of life for any large and active organism. The difficulty of solving the problem is increased by the fact that no large reserve stock of oxygen can be maintained. In the case of a human being there may a food supply in the tissues sufficient to sustain life for weeks, even though no new supply is taken in. There is water enough in the body to maintain life for days; but if the supply of oxygen is shut off, life can be continued only for a very few minutes on the stock of oxygen contained in the body. So narrow is the space between abundance of oxygen and death from oxygen starvation. In a cold-blooded animal—with which the lake ought to be compared—processes of respiration are slower, but the relative situation is not materially different. The result of these conditions is that in any large animal enormous surfaces must be provided for the absorption of oxygen and there must be a very perfect mechanism for its distribution. Such respiratory systems exist in a great variety of forms, many of which are extremely complex and efficient. In the case of man the absorbing surface of the lungs is said to amount to about two thousand square feet—an area as great as that of floor, ceiling and walls of a room 20 feet square and 15 feet high. The necessity for arrangements for a large absorbing surface increases with the size of the animal, since in a large organism the area of the general surface is far smaller in proportion to its mass than in a small organism of the same shape. In a lake, whose size is enormous as compared with that of any living being, the absorbing surface is very small as compared with its mass; being only the upper surface of the water. The lake is, therefore, at a great disadvantage in the matter of absorbing oxygen as compared with the animal. Still further, all higher animals, both cold-blooded and warm-blooded, contain in their blood some chemical substance which has a special affinity for oxygen and which can rapidly pick up large quantities of it. Such a substance is wholly lacking in the water of the lake, whose respiratory power is correspondingly small as regards both the rapidity with which oxygen can be taken up and the amount which can be absorbed. It is indeed true that water will absorb, according to the general laws of the absorption of gases, about twice as much oxygen as nitrogen under similar conditions. This fact allows the lake to take in a larger stock of oxygen than would otherwise be possible, and that part of the atmosphere which is dissolved in the lake contains about one third oxygen instead of one fifth, as is the case outside. But even this amount is very little in comparison with the enormous volumes which a substance like hemoglobin can take up. It is also true that the mass of the water of the lake, in comparison with the mass of the organisms which draw their oxygen from it, is relatively far greater than the mass of the blood

with reference to that of the cells which take their oxygen from it. Yet is it none the less true that the supply of oxygen in most lakes is very small as compared with that of an animal, and the mechanism for renewing it is always very inefficient as compared with the demand for the gas.

The disadvantage of the lake in the matter of respiration appears still more clearly when we consider the means of transporting the oxygen from the region where it is absorbed—the surface—to the deeper parts of the lake, where much of it is to be used. The animal shows a complex and very efficient mechanism for the circulation of the blood; an apparatus whose complexity and efficiency are in large measure determined by the necessity for a rapid distribution of the oxygen and a rapid disposal of the gaseous wastes of the body. In the lake the means of transport are three: diffusion, by which the gas is slowly passed from point to point in the water independently of currents; currents produced by the wind; and convection currents, produced by the cooling of the surface water to a temperature below that of the water beneath.

Diffusion is a process which operates rapidly when the distances are minute, but whose efficiency decreases greatly as the distances increase. In our lungs, or the gills of a fish, for instance, where the distance between blood and air is measured in thousandths of an inch, the process of diffusion goes on with great rapidity. But where, as in the lake, the distances are measured by inches or by feet, or even by scores of feet, the process is practically worthless for the processes of distribution. By diffusion alone oxygen would penetrate the lake only to the depth of a very few feet in a whole season. While diffusion, therefore, plays an active and important part in the exchange of gases between the individual plant and animal and the water immediately surrounding it, it has little or nothing to do with the general circulation of gases within the lake.

During the fall, when the lake is cooling, convection currents aid materially in carrying oxygen down to considerable depths. The surface water, saturated with oxygen, cools, becomes heavier, and sinks, carrying the gas with it. The same process takes place at night in summer, but ordinarily to very small depths. In general, we may say that during early and mid-summer, before the period of general cooling begins, these processes do not extend to greater depths than ten or fifteen feet. At the season, therefore, when vital processes are most active and the need for oxygen is greatest, convection currents afford a minimum of assistance in distributing it. The main reliance, therefore, for the distribution of oxygen is in the third factor, the wind. This, as already said, is very efficient when the lake is uniform in temperature; but during the spring, as the lake warms, it becomes in-

creasingly ineffective, and during the summer its action is confined to the upper warmed layer of the lake, and the lower, cooler, water is wholly shut off from the direct influence of the wind currents.

These facts show that an inland lake has an extremely inefficient apparatus for absorbing and distributing oxygen, and the net result is that in many lakes the amount and character of the higher life which the lake will support is conditioned by the amount of oxygen which the lake contains rather than by the amount of food which it can produce. The oxygen in the lower and cooler water of the lakes can not be renewed between spring and fall. This amount would be indeed ample to sustain a large amount of animal life in full activity. But its use can not be confined to the necessities of ordinary life. The processes of decomposition draw upon it much more heavily than does the animal or the ordinary vegetable life. All the plants and animals of the upper water, which die and sink into the deeper strata, the leaves blown into the lake, and the material washed in from the shore, decompose in the cooler water and in the process of decomposition use up a great amount of oxygen. This depletion of the stock of oxygen goes on with a rapidity which varies with the amount of decomposing matter dropping into the lower water, which to some extent regulates the rapidity of decomposition, and, with the depth of the water, on which depends the quantity of oxygen contained in it. Each of these factors may and does differ in different lakes, but the result is that in a very large proportion of our inland lakes the bottom water loses its stock of oxygen comparatively early in the season and becomes uninhabitable for higher animals. This fact excludes from our lakes a good many kinds of animals which they might otherwise support, and very greatly limits the quantity of the higher life which the lake is able to maintain. A lake which loses its bottom oxygen, for example, can not support a fish such as the lake trout, which must retire to the deeper and cooler water during the summer. To causes such as this may probably be attributed a considerable number of our failures in the planting of fish in our inland lakes. From causes such as these, the whole of the lower water, containing half, or more, of the volume of the lake, may become uninhabitable during the season when life is most abundant; and the quantity of life which the lake supports may be correspondingly limited.

Still further, since the rapidity with which the oxygen is exhausted depends on the amount of material which is deposited in the lower water, those lakes whose upper water contains the greatest quantity of vegetable life and which can therefore support the greatest amount of animal life, use up the oxygen of the lower water most rapidly. It looks, therefore, as if we were in a somewhat unfavorable situation as regards the possibilities of higher life in the lower water of inland

lakes. Those lakes whose food supply is such that they are capable of supporting large quantities of animal life—I may say for our purposes, large numbers of fish—are likely from that very fact to exhaust the stock of oxygen in the lower water, which thus becomes uninhabitable; while those lakes whose lower water is fully habitable are likely to be so poor in organic life that they can support only a limited number of fish. It may be that further study will show that this relation is not so unfavorable as it now appears, but at present we must face the probability that it exists.

A noteworthy exception to this statement should be made in the case of very deep lakes—lakes two hundred or more feet in depth—in which the quantity of the lower water is so great and the consequent amount of dissolved oxygen is so considerable that no ordinary amount of decomposing material can exhaust it or materially reduce it. This is the case, for example, with Green Lake (237 feet in depth) in Wisconsin, and the same statement would doubtless hold for the deep lakes of New York and similar bodies of water. Such lakes may support an abundant population of fish both in the warmer and in the cooler water. If they do not do so, the fault does not lie with the oxygen supply.

Thus we see that if we desire to determine the capacity of a lake for the development of higher life, we must consider not only its capacity for food production, but also its respiratory conditions. It may be that an imperfect respiratory mechanism renders a very large share of the bottom of the lake wholly uninhabitable for animal life during the warmer part of the year; that while, for instance, mud-living insect larvæ may be found in the mud around the lake to a depth of twenty or thirty feet, they are excluded by the absence of oxygen from the entire bottom of the lake beyond this depth, an area of perhaps many square miles. The supply of food which the lake offers to the higher animals may thus be greatly limited by the lack of oxygen. It may be true also that the greater part of the volume of the water of the lake is uninhabitable for similar reasons, and that a lake whose surface appearance would indicate that it is capable of supporting enormous quantities of fish may be very considerably restricted in this respect by its respiratory capacity. Each lake should be studied as to both food and oxygen if an intelligent economic use is to be made of its waters; and when this is done, the possibilities of use will often be found to depend on the respiratory mechanism.

I have said nothing on another side of the methods of absorbing and transporting gases in a lake. The same processes which take oxygen from the surface bring waste gases to it and they are as efficient, or as inefficient, in the latter operation as in the former. Processes of absorption and transportation have much to do with the story of the

complex relations of carbon dioxide gas in the lake. These matters, however, can better be spoken of under internal respiration. I need only say here that the accumulation of waste gases in the lower water does not seem to affect life unfavorably if there is plenty of oxygen present also. Respiratory inefficiency limits life in a lake because of lack of oxygen rather than because it allows poisonous gases to collect in large quantities.

The subject of internal respiration deals with the changes of gases within the lake itself and with the manufacture of gases by the organisms which inhabit it. No branch of physiology is more intricate and none less understood than is that of internal respiration. This is true also of the internal respiration of the lake. The gaseous exchanges and the manufacturing operations in the interior of a lake are far more complex than those of any animal. From the water living beings are drawing supplies of gas, each after its kind, and to the water each is contributing gases differing in amount and composition. Animals are withdrawing oxygen from the water and giving carbon dioxide to it. Algæ are repeating this process by night and exactly reversing it by day. Fungi and bacteria are using oxygen in the course of their internal vital activities; they are employing far larger quantities in the fermentative processes which they maintain. The innumerable chemical changes included in decomposition and fermentation, going on under all sorts of conditions, involving numerous kinds of materials, and operated by various organisms, are adding to the water gases of different kinds and in varying proportions. The upper water, the lower water and the mud present very dissimilar fields of work to the organisms which inhabit them. It is, therefore, impossible even to attempt a picture of the internal respiration, with its countless operations, each adding to or subtracting from the sum of gases in the lake; in an intricate network of processes, consecutive, correlative and antagonistic; connected by relations which cross and interlock at a thousand points. I shall speak of only a few detached topics.

I have said that the oxygen of the lake is absorbed from the air. This is true so far as the main stock of oxygen is concerned; but a lake has a second source of oxygen which is always considerable and which in certain places and relations may become important. The green plants which inhabit the lake are able to take up carbon dioxide from the water, and under the influence of light they can use it in the manufacture of starch, setting free oxygen in the process. In lakes which contain an abundance of algæ, considerable quantities of oxygen may arise from this source and this manufactured oxygen may play an important part in the vital history of the lake.

Consider the effect of the addition of this power of the algæ to the numerous factors which are affecting the supply of oxygen in the upper

water of the lake in summer. If the oxygen of this region is studied, it rarely happens that the quantity found is the amount which would be theoretically expected, according to the laws of the absorption of gases by water at different temperatures. It is sometimes largely in excess of the theoretical amount, and sometimes is considerably deficient. The fact is that the amount of oxygen in the upper water of the lake is the resultant of very numerous and variable forces. The lake may or may not be absorbing oxygen from the air. If saturated, it will give off oxygen to the air as the water warms, or will take it in as it cools. Both of these processes go on somewhat slowly, and the oxygen is not given off or absorbed as rapidly as the water warms or cools. Into the water the green plants are discharging oxygen during the hours when the light is sufficiently strong; from the water both plants and animals are taking oxygen to assist their vital operations; and the process of decomposition is aiding to exhaust the stock of oxygen. Thus the amount present at any given moment will depend on the relative value of these forces; some of them positive; others negative; and all varying not only from day to day, but from hour to hour. Nor do these factors exhaust the list. The wind has something to do here; during a calm period the oxygen content of the upper water may differ from that of a stormy period. The vital condition of the successive crops of algæ, as they come and go, may determine for the time the predominance of the manufacture of starch, with accompanying liberation of oxygen, or decomposition, with partial exhaustion of oxygen. Thus the ability of the green plant to set free oxygen into the upper water may be of great value in maintaining the supply of the lake.

This power may be far more important in the lower water. If the transparency of the water and the thickness of the warm layer are such that a good deal of light can penetrate to the colder water, algæ will be able to manufacture starch in the upper part of this stratum. Thus in the region which is practically cut off from access to the atmosphere, large amounts of oxygen may be set free. There may be enough not only to serve the ordinary needs of the stratum, but the water may be saturated or even oversaturated with the gas. To illustrate this point I give a diagram (Fig. 1) showing the vertical distribution of oxygen in Elkhart Lake, Wisconsin. This figure shows clearly the position and amount of the manufactured oxygen, and the addition which it makes to the thickness of that part of the lake that has abundance of oxygen. Lakes whose habitable portion would otherwise be only twelve to twenty feet in thickness may have this depth nearly or quite doubled by the presence of the manufactured oxygen. The plants in this undisturbed cooler water find a peculiarly favorable situation for growth. They obtain for their food the products of decomposition,

which is taking place rapidly in the lower water; and not infrequently a far larger amount of organic life may be found in these strata than in any other portion of the lake. This process is necessarily limited

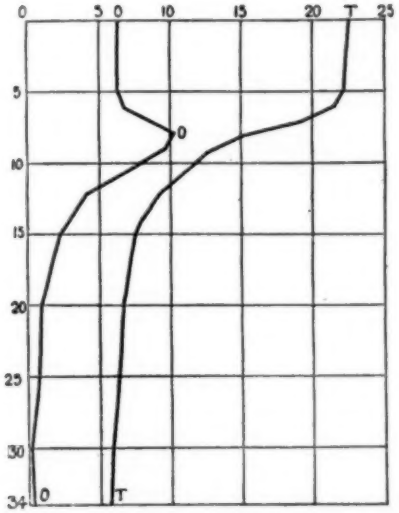

FIG. 1. ELKHART LAKE, Aug. 23, 1905. The vertical spaces indicate the depth in meters. The horizontal spaces indicate cubic centimeters of oxygen per liter (parts per thousand of volume), as shown by the line *O---O*. They also indicate the temperature in centigrade degrees, as shown by the line *T---T*. The upper, warm layer of water is about 6 m. thick; the thermocline extends from 6 m. to about 10 m. The presence of the manufactured oxygen is very plainly seen in the space between 5 m. and 12 m.; the amount of oxygen rising to a maximum of over 10 c.c. per liter at the depth of 8 m. The relation of this gas to the temperature of the water and the consequent stratification is clearly shown.

to lakes whose upper warm layer is thin, and is confined to the upper part of the cold water, since only there can the light have sufficient intensity to carry on the operation. But even thus restricted, it is of great value to some lakes.

I have said little hitherto of the carbon dioxide—a gas whose importance is quite equal to that of oxygen—and now can only sketch a part of its complex story. This gas plays many rôles in the respiration of the lake. It is at once the waste product of the tissue activity of plant and animal, the product or by-product of decomposition, and the indispensable food of green plants. The lake may obtain the gas from the air, and to some extent does so. Carbon dioxide exists in the atmosphere in very small amount—about four parts in 10,000. Minute as this quantity is, the land plants are able to secure from it ample supplies of carbon. The movement of the air is so free and such enormous quantities pass over the surface of the plants, that they readily pick up the gas in large amounts. But the situation of the algæ and other plants of the lake is very different, as they must secure their

carbon dioxide through the intermedium of the water. This readily absorbs large quantities of the gas. But the percentage existing in the air is so small, the absorbing surface of the lake is so restricted, and the means of transport are so poor that the lake is quite unable to take from the air enough carbon dioxide to maintain a vigorous growth of plants. The lake is forced to depend on its own resources to a large degree for this plant food. Fortunately, these resources are considerable. Great amounts of carbon dioxide are manufactured in the lake and these may be utilized as food by the green plants. Thus there is kept up in the lake a sort of internal circulation of carbon dioxide; the stock of the circulating medium being increased and replenished by additions from outside. The activities of animals and the processes of decomposition liberate the gas, which is taken up and manufactured by the plants into organic substances; and these in turn serve as food and as material for new decomposition; while from the air the water may be absorbing new supplies of carbon dioxide to make good the losses of this process. Thus under normal conditions, the lake would return little or no carbon dioxide to the atmosphere, but would utilize within itself all that it manufactured or absorbed, at least until the plant life became so abundant as to be limited by other causes than that of food supply.

If this were all, the story would be quite simple and quite to the advantage of the lake. But it is by no means all the story; on the other hand, so far from being forced to solve problems associated with an oversupply of carbon dioxide, the lake has to encounter many difficulties in securing an adequate supply of that gas, and is able to meet them only very partially and imperfectly. Since the plants are able to utilize carbon dioxide in the manufacture of starch only during the hours of sunlight, considerable quantities may escape into the atmosphere during the night. But this is not the only disadvantage as regards the supply of carbon dioxide, with which the plants of the upper water have to contend. By no means all, or even the greater part of the organic matter which they manufacture decomposes in the upper, warmer stratum of the lake. As the plants and animals die, they sink into the lower and cooler water before any great part of the decomposition has been completed. The carbon dioxide which is there produced is discharged into this bottom water. It can not be used there by plants on account of lack of light. The same imperfections of transportation which prevent the access of oxygen to the cooler water in summer make it impossible to transport the carbon dioxide produced there to the upper stratum, where it can be utilized. In certain lakes, indeed, a small portion of this gas may be used in the cooler water, as I indicated above, but, in general, the upper water, as a result of this process, is growing poorer during the summer in the materials on

which plants feed, both gaseous and other. These are for the time locked up in the lower water and so withdrawn from the circulation of life. In the autumn, as the lake cools and the thickness of the circulating stratum increases, these matters become available so far as they lie in the upper part of the cooler water, and when the lake has become uniform in temperature to the bottom, and the water is turned over by wind, the whole of this accumulated stock is available for the purposes of plant growth. This may be one of the reasons for the abundant growth of algæ, which takes place in the autumn. But while the non-gaseous products of decomposition may be wholly utilized in the lake, the carbon dioxide is hardly likely to find full use. When it once becomes distributed through the water and new portions of the water are being continually exposed to the air, considerable quantities must escape during the hours when plants are unable to avail themselves of it.

Thus the rudimentary character of the circulatory apparatus of the lake forms an insuperable obstacle to the best utilization of the food supply. It is therefore easy to see why life is relatively so abundant in large and shallow lakes, in which the circulating methods have a maximum efficiency. The fact that these lakes are shallow permits a larger growth of life, since not only is the water available but plants in large quantities may grow from the bottom. But of even more importance than this relation is the fact that since the entire mass of water is kept in circulation by the wind, all the products of decomposition are immediately available for use and the life cycles of the plants may go on as rapidly as their rhythm of growth will permit. The carbon dioxide and other products of decomposition, instead of being locked up in the deeper water and set free only during that season which is least favorable for growth, are utilized immediately and are employed over and over again through the warmer season as the cycles of life and death of the individual plants recur. It is plain that lakes whose margin is wide and shallow, though the middle may be deep, must stand next to the shallow lake in efficiency of means of transportation. Much growth takes place in the shallow waters, much decomposition goes on there, and relatively little of the organic matter sinks into the deep water, to be withdrawn from circulation. Least favorably situated is the deep and steep-sided lake, whose cold depths are continually swallowing almost all of the products of the summer's growth, and give them back for use, only late in the autumn when the season for active life is passing away.

Some lakes may find aid from another source in the task of securing carbon dioxide. Most natural waters contain a certain amount of calcium and magnesium salts in solution, and, for the greater part, these exist in the form of bicarbonates. Lakes whose water is hard

contain a considerable amount of these bicarbonates and soft-water lakes have little or none. In hard-water lakes it is found that during the growing season, when algæ are active, the upper water contains no free carbon dioxide, but is, on the contrary, alkaline, when tested with phenophthalein as an indicator. This alkalinity comes from the fact that one molecule of carbon dioxide has been withdrawn from part of the bicarbonates, converting them into carbonates. It appears that the algæ are able to effect this reduction and that they can obtain their supply of carbon from the carbon dioxide of the bicarbonates dissolved in the water. This fact introduces a wholly new feature into the story of the food supply of the plants. It provides a chemical carrier for the carbon dioxide which may carry this gas somewhat as the hemoglobin carries oxygen in the blood. All carbon dioxide set free in this alkaline water as the result of decomposition or other processes, will be taken up immediately by the carbonates. Thus if plants are not at hand to utilize the carbon dioxide at once, it is not lost but kept until it is needed. So in the night, the lake is able to retain all the carbon dioxide set free and which the plants do not use at that time.

Such alkaline water has also a great advantage in absorbing carbon dioxide from the air. It presents for absorption, not merely the relatively weak and slow powers of the water for dissolving the gas, but the eager and vigorous powers of chemical affinity. And until these alkaline carbonates are saturated, no free carbon dioxide will appear in the water to diminish the rapidity of absorption from the air. Thus hard-water lakes have an advantage over soft-water lakes in the matter of securing plant food, and in fact the population of soft-water lakes is smaller than that of lakes of the other type.

It is worth while to devote a few words to gaseous products of decomposition other than carbon dioxide. So long as the bottom water contains an abundance of oxygen no other gas than carbon dioxide is produced in appreciable quantities. But as the oxygen becomes greatly reduced or wholly disappears, decomposition continues in new forms and under these conditions of anaerobic fermentation other gases may be developed in considerable amounts. It is apparently true that carbon monoxide may be present in the lower water of lakes in appreciable quantity, and it is certain that marsh gas is developed in large volumes in lakes where the amount of fermentable material is large and where the oxygen disappears from the lower water early in the season. These gases first appear near the bottom, where decomposition is going on most actively and where the oxygen first disappears. In many lakes they are found only in small quantities and close to the bottom, but in proportion as the amount of decomposable matter increases, they are found at considerable distances from the bottom, and in certain lakes all of the water below the thermocline may contain

marsh gas in appreciable quantities, often becoming very great as the bottom is approached. These gases do not seem to have any very definite unfavorable effect on the life of the lake. Diffusion is so slow that they do not reach the upper water and experiments indicate that their presence in the lower water adds little, or nothing, to the unfavorable conditions brought about by the absence of oxygen.

It should be noted that these processes involve a loss of material for plant food. Carbon dioxide, produced by aerobic decomposition, is available for plant food in the lake, or, if not there, then elsewhere as part of the general stock of that gas in the atmosphere. But marsh gas has no such relation to plants and all substances converted into it are lost to the cycle of life. Its production means just so much reduction of the food supply of the lake. The same may be said of the carbonized, peat-like substances produced from the partial decomposition of plants under water. So long as these remain under water, they are practically withdrawn from the food supply. Against all these influences which tend to diminish the stock of food for its inhabitants, the lake is contending, but with imperfect means and only partial success.

I have thus hastily and imperfectly sketched the respiration of an inland lake, not because the story is known with any fullness or completeness, but partly because our present knowledge, imperfect though it is, shows that the subject is one of great scientific interest; partly also because many practical hints regarding the utilization of lakes in fish culture can come from our knowledge of respiratory conditions. We are accustomed to think of the food-producing capacity of the lake as the factor which determines the kind and amount of the crop of fish which it can produce. It is a somewhat new thought to me, and I have no doubt that it is equally new to many of you, that the respiratory capacity of the lake may have even greater influence in this matter than has the capacity for the production of food. Yet it is plain that such is the case and that a knowledge of the respiratory conditions of the lakes in which our fish are to be planted is necessary if the best results are to be reached.

THE UTILIZATION OF AUXILIARY ENTOMOPHAGOUS INSECTS IN THE STRUGGLE AGAINST INSECTS INJURIOUS TO AGRICULTURE[1]

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I. The Rôle of Entomophagous Insects in Nature

If phytophagous insects could develop and multiply without hindrance in proportion to their natural reproductive power, in a short time they would cause all species of terrestrial vegetation to disappear. The multiplication of these destructive forms is very fortunately kept within limits compatible with the existence of plants by the presence of other insects, predatory or parasitic, which places a check on their propagation.

The capacity for prolification of entomophagous insects is itself very considerable: their eggs may often be counted by hundreds or even by thousands; moreover, as several of the species of parasites often attack a single species of plant-feeding insect, it is certain that the latter would in its turn become very rapidly annihilated if the parasites were not themselves held in check by hyperparasites, and if they were not repressed in their spread by all the obstacles that render their struggle for existence more difficult than can be imagined.

The rôle of entomophagous insects is of the first importance, whether from the point of view of the economy of nature or from the point of view of utility to man.

Some, like the Carabidæ and Coccinellidæ, are predatory. They destroy for food the insects which they attack, and the benefit derived from their action is immediate.

The others, which are represented both by the hymenopterous and dipterous parasites, lay their eggs in the interior of developing insects, or in their near neighborhood, and the larvæ which hatch from these eggs nourish themselves at the expense of their hosts, accomplishing their death at a more or less advanced stage of their evolution. In this case the benefit brought about is sometimes immediate, as in certain species of minute Hymenoptera (*Teleas, Tetrastichus,* etc.) which lay their eggs in the interior of eggs of other insects and

[1] Translated from "The Annals of the National Agronomical Institute" (Superior School of Agriculture), Second Series, Vol. VI, Part II, Paris, 1907, pp. 281–354.

complete their development within the eggs. The phytophagous insect is then killed within the egg, and the plant thus completely escapes its depredations.

Much more frequently it does not immediately stop the growth of its host; it introduces its egg into the phytophagous insect and in the more or less advanced stages of its development, either during the embryonic period (*Encyrtus fuscicollis,* divers Platygasters), or frequently during the larval or nymphal period (Ichneumonids, Braconids, etc.). The phytophagous insect which carries in its interior the larva of the parasite, continues to grow and to feed upon vegetation, and is killed by the parasitic insect only when the latter has reached its full development, and when the host has done all the damage it is capable of doing during its existence. The benefit accomplished by the parasite is manifest only in the following generation, and consists in the suppression of the descendants that would have been mothered by the phytophagous larvæ, if they had been able to develop until their transformation into adult insects.

Whether they belong to one or another of these catagories, the predatory and parasitic insects play a regulating rôle that is useful and remarkable. When, on account of cultural conditions or climatic circumstances or other influences, the phytophagous species tends to increase beyond the average, it thus furnishes conditions eminently favorable to the multiplication of the parasitic species, and that in its turn causes the phytophagous form to decrease.

In a very interesting, but insufficiently known work, Bellevoye and Laurent (1897) have shown that it is not necessary that the parasite should have a greater fecundity than the phytophagous species in order to bring the latter back to its normal condition when it has exceeded it. As paradoxical as is this assertion, with a fecundity simply equal and even inferior, it may rapidly reach the point of annihilation, if other factors and other conditions do not interfere to interrupt this action. All other things being equal, nothing prevents the development of the parasites, so that by their work a greater and greater quantity of the plant-feeding species are destroyed each year. In order to state this fact precisely let us, with the authors just cited, take as simple an example as possible, that of an invasion of the caterpillars of *Bombyx.* Suppose that at a given period the proportion of parasitized caterpillars is one fourth, and that the parasites have placed a single egg in each caterpillar. Of 8 chrysalids, 6 will give out *Bombyx* and 2, parasites. We will suppose that of the 6 moths there are 3 males and 3 females; and of the 2 parasites, 1 male and 1 female. Let us suppose that the fecundity of the parasitic species is equal to that of the host species, and that the number of eggs laid by a female of each of the two species is 100.

We will have for the first year 300 caterpillars, of which 100 will be parasitized. That will give, as eventually issuing, 200 moths (100 females) and 100 parasites (50 females).

The second year there will be 100 times 100 = 10,000 caterpillars of which 50 times 100 = 5,000 will be parasitized. That will be 5,000 issuing moths and 5,000 issuing parasites with 2,500 females of each species.

The third year the number of caterpillars will be 2,500 times 100 = 250,000 and all these will be attacked by parasites so that there will be no moths issuing.

This theoretical example shows very well how an injurious species, after having increased in threatening progression during several years, immediately after having reached its maximum can suddenly disappear in a short time under the influences of the parasite. The diminution of food also contributes to limit the propagation of the plant-feeding species, and may hasten the inevitable triumph of the useful species. Every one who is interested in agricultural entomology knows that incidents like this are frequently observed in nature. When an insect has been very injurious for two or three years, and has multiplied to the point of taking the proportions of a veritable plague, it disappears, usually in a sudden manner at the moment when the alarm which it has provoked has reached its highest degree. Experience has shown that it is almost always to the work of parasites that these rapid retrocessions of injurious species must be attributed.[2]

The damage of the Hyponomeutas to fruit trees is almost always stopped at the end of two or three years by Tachinids, or other parasites. The same thing occurs with the Bombycids which devastate coniferous forests.

A remarkable example of the same phenomena is shown with the Cecidomyiids of cereal plants.

After the destruction caused in Vendee and in Poitou by the Hessian fly and the oat midge, in 1895, these insects disappeared almost completely, and the farmers had no further cause to complain of their presence.

Now I ascertained that an enormous majority of the pupæ which should have been in the grain at the end of 1894, or the beginning of 1895, were parasitized. So much so that it was difficult for me to find specimens with which to carry on certain studies in which I was engaged at that time. Having collected in March, 1895, in the suburbs of Poitiers, some stubble from the harvest of 1894, remaining through the winter and containing an enormous quantity of the pupæ of the flies, I obtained in the jars in which I had this stubble enclosed, only a

[2] Aside from parasitic insects, bacterial or fungous epidemics may intervene in a similar manner, but the consideration of these does not fall within the province of this article.

cloud of parasites which came out during the months of April and May.

If one would take the trouble to observe, one could multiply similar examples without difficulty.

It must be remarked that in the case of which we have just spoken, the injurious species are very injurious only from time to time in a rather periodical manner. Several years will occur in a given region when they are not mentioned. Then, under the influences of certain conditions, they multiply for two or three years in an excessive way, giving rise to terrible invasions, until the parasites favored by this great development of the host species become themselves sufficiently multiplied to bring about the retrocession. This repressive and regulating action of the parasite, having for its object the limiting of the increasing abundance of the plant-feeding species, moves then in a successive periodical manner, which recalls a little the action of the siphon of an intermittent fountain. This type of injurious species, with great invasions more or less separated and presenting a periodical character, is met with especially with those species which attack plants cultivated upon a very large scale, and corrects an unstable equilibrium which man himself has provoked by the establishment of great homogeneous cultures. Exception, however, should be made in regard to certain migratory and omnivorous species, such as the grasshoppers and crickets, whose invasions seem to exist during all time and without any correlation with cultural conditions.

In other cases which more nearly approach the general and primitive law of nature, the injurious species maintains always about the same rank, and the fluctuations which it presents are only of secondary importance. The parasites act as a moderating check to the continued increase, and prevent the injurious species from multiplying in an excessive manner. They are themselves present in almost constant number from one year to the other. Their rôle is not only to bring back an injurious species to a small number of indidivuals when it has passed the mean, but to hold it constantly at a numerical point much below that which it would reach without their presence.[3]

It is very certain, however, that in nature all the intermediate stages between these two types just mentioned are to be found, and these two types themselves, as we admit, are more theoretical than real.

[3] The condition by which the fraction of parasitized insects remains constant from year to year is represented by the equation: $\frac{c}{b} = \frac{a-1}{a}$; c representing the number of eggs laid by an individual of the parasitic species, b the number of eggs laid by an individual of the plant-feeding species, and $1/a$ the proportion of parasitized insects. (Bellevoye & Laurent, *loc. cit.*) In other terms, if a quarter of the insects are parasitized, it would be necessary, in order that this proportion should remain constant from year to year, that the fecundity of the parasite should be to that of the host as three is to four.

The conditions and factors which control the relations of beings among themselves are so numerous and so complex that to interpret them and render them intelligible one is forced to speak more or less theoretically in considering only certain of the causes and in momentarily omitting the others.

In fact, the regulation can in no case be considered as the exclusive result of the action of any given parasitic species, of which the fecundity will be proportioned to that of the host species and in such relation that it maintains a constant numerical tax.

The fecundity of the parasitic species is only one of the factors which determines this equilibrium. If it is true that it is of prime importance, that fact should not prevent us from taking account of the others. There are a number of these, as follows:

First.—The hyperparasites, or secondary parasites, living at the expense of the primary parasite, and having themselves tertiary parasites.

Second.—The coparasites, that is to say, other species living in the same host.

Third.—Other plant-feeding species occurring with the host species.

Fourth.—The enemies of all insects (insectivorous birds, etc.), attacking both the plant-feeding species and the parasitic species.

Fifth.—Climatic conditions influencing in a favorable or in an unfavorable way either the host species or the parasites, the hyperparasites, or the enemies of all kinds liable to attack the insect.

Sixth.—The rapidity with which the generations are developed,—of the host species, on the one side, and the parasitic on the other.

Seventh.—The tendency in the plant-feeding species to retard the development of certain individuals of a given generation for a longer or shorter time.[4]

[4] Factor No. 7, taken alone or combined with the preceding factor, has a prime importance in preserving the host species from destruction by the parasitic species. Three examples will serve to illustrate this:

First Example.—Encyrtus (*Ageniaspis*) *fuscicollis* is a hymenopterous parasite whose power of prolification is immense, since, as I have shown in an earlier memoir, it presents the very exceptional phenomenon of polyembryony, that is to say, that a single one of its eggs can give birth to more than 100 individuals, capable of multiplying in this way.

Now this *Encyrtus* lays its eggs in the eggs of a moth of the genus *Hyponomeuta*, which has only a single generation each year, as has the *Encyrtus* itself. Under these conditions it may be asked how the *Hyponomeutas*, instead of being promptly annihilated, are, on the contrary, capable of multiplying in certain years to the point of being destructive to fruit trees during their larval stage, and this in spite of a number of other parasites, particularly Tachinids. The reasons are certainly numerous; but the one to which we wish to call attention is, that the time of the swarming of the *Encyrtus* is notably shorter than the egg-laying period of the *Hyponomeutas*. However immense may be the number of Encyrtids that appear in a season, one may be certain that all of

Eighth.—A faculty similar to the preceding which the parasite may possess.[5]

the eggs of the *Hyponomeutas* are never parasitized, and the adult generation of the *Encyrtus* will already have disappeared while the *Hyponomeutas* still continue to lay eggs, which will thus escape the parasite.

Second Example.—With the Hessian fly, a small dipterous insect whose larva is extremely injurious to wheat, the generations succeed one another the whole year, and under particularly favorable conditions there can be five or six generations in a single year. However, the time necessary for an individual to perfect its development is extremely variable, according to conditions in which the pupæ find themselves, and especially in regard to their position on the plant—whether on the green part or near the earth or even dry stubble. Some can complete their development in two weeks, while others, finding the conditions of dryness exceptionally long, wait even as long as two years before issuing. The hymenopterous insects, living at the expense of the insect, which may appear in innumerable quantities, have, on the contrary, only two generations each year at the maximum, and appear only at a definite time, and during a lapse of time of usually short duration. Now, since the parasites never attack more than one of the developmental stages of the insect—egg or larva, according to parasitic species—it results, from what precedes, that there will always be, at the period of egg-laying, existing individuals of the species which will escape them because they are in a developmental condition in which they are not pierced; and when the generation of parasites has passed, these individuals will remain unharmed and constitute the indispensable reserve for the perpetuation of the species. It is not necessary that this reserve should exist throughout the range of the plant-feeding species. On the contrary, they may be annihilated in certain localities by a combination of climatic conditions or factors of some other nature having an unfavorable influence, and it is in this way that the local disappearance of certain species, of which this one is an example, is to be explained.

Third Example.—In the preceding case the average conditions, and in particular the relative dryness, play a part of the first rank in the determination of retarded development, and the adaptation of the plant-feeding species enables it to react in a more or less energetic manner to external influences. In other cases the plant-feeding species has acquired a great variability in the time necessary for the development of individuals. This variability, which appears to be independent of average conditions, consists in reality in the fact that different individuals present a variable power of reaction to identical external influences.

It is thus that, according to Boisduval ("Essay on Horticultural Entomology," Paris, 1867, p. 15), the chrysalids of *Bombyx everia* and *lanestris*, which cause great damage in Germany, issue in a very irregular manner. "One sees," says he, "moths of these Bombycids issue in September after three months of metamorphosis, others in the spring of the following year; but what is more astonishing is, that from the same egg laying, from the same brood of caterpillars, reared under the same conditions, the moths have issued during seven years in April and September—a wise foresight on the part of nature, which does not wish to expose the species to sudden destruction."

[5] This factor, which favors the parasitic species, is in conflict with factor No. 7. Some very remarkable examples of this have been given me by M. Künckel d'Herculais concerning egg-feeding parasites of locusts (Cantharids, Clerids and Bombyliids), the development of which in certain cases can be retarded for several years, thanks to a condition of torpidity which the larvæ

There exists an intimate relation between all these conditions, and this relation binds in a particularly striking manner the plant-feeding insect and parasites which live at the expense of the latter. The harmony which results from the mutual adaptation of these beings should not be surprising, since it is the condition *sine qua non* of the existence of the species. From the reciprocal actions which they exercise upon one another, results the equilibrium in which they are maintained.

II. Perturbations brought by Man in the Natural Equilibrium

The intervention of man in disturbing the laws of nature is capable of breaking this natural equilibrium, and of bringing about in the existing order a perturbation from which he is perhaps the first sufferer of serious consequence. This rupture can be occasioned by two principal causes: (1) by new conditions created for insects by cultures; (2) by the accidental carriage of certain species from one country to another.

1. *Perturbations provoked by New Conditions created by Cultures; Methods bringing about the reestablishment of the Equilibrium*

Man, in planting over a vast extent of country certain plants to the exclusion of others, offers to the insects which live at the expense of these plants conditions eminently favorable to their excessive multiplication; for he diminishes in their favor the difficulties of their struggle for existence and often favors their alimentary specialization, while the food-plant, in the conditions which it finds itself, is not always capable of reacting by defensive adaptations of sufficient compensating value.

In this case, man, in order to regain the equilibrium favorable to his own interests, should have recourse to a regular rotation of crops, destined to interrupt the life cycle of the injurious species, and to all methods possible to increase the resistance of the plant. But also the beneficial insects whose useful rôle is incomparable should be watched. It is necessary to aid or at least to start their work; and, finally, in any circumstances it is necessary to know them in order to protect them in a judicious way, and above all not to destroy them by inopportune cultural practises.

Protection of Beneficial Insects.—Apropos to the Hessian fly, we may enter into. "The retarded development of these parasitic larvæ," says Künckel, "enables the successive issuing of adult insects during several years, and is evidently in close correlation with the appearance of the locusts; the latter, decimated, fly from their enemies to reproduce far away; the former awaiting their return to insure the well-being of their progeny; thus is established a regular balance between the multiplication of the locusts and that of their egg-feeding parasites, which assures the perpetuity of both species."

have elsewhere insisted upon the fact that one of the measures most often recommended—the destruction of the stubble remaining in the field after the harvest—may have unfortunate consequences, for doing this in a tardy manner one risks intervening at a moment when all of the flies have emerged and have abandoned the stubble, exposing to destruction only the parasites whose part would have been to stop the invasion the following year.

Kieffer has pointed out a remarkable analogous fact for a Cecidomyiid, namely, *Diplosis tritici,* attacking not the stubble, but the grains of wheat, and has shown that one of the measures which has been advised—burning the debris after the threshing—has only an injurious effect, for while it is true that this debris contains pupæ of the midges, it should be remembered that the healthy and nonparasitized larvæ of these flies transform in the ground, while those which remain in the heads are, on the contrary, parasitized.

In the cases which we have just mentioned, the protection to be accorded to the parasites consists solely in abstaining from inopportune measures capable of bringing about their destruction without any advantage whatever. In other cases it is an active protection which has been advised, and which comprises operations destined to insure the survival of the parasites.

It is in this way, for example, that Decaux, struck by the multitude of ichneumon flies, or Braconids, which came out of the buds of apple attacked by *Anthonomus,* advised, in place of immediately burning these buds as was generally done, preserving them in boxes covered with gauze, raising the latter from time to time during the period of issuing of the parasties so as to permit them to escape. In 1880, he put this method into practise and collected in Picardy buds reddened by the *Anthonomus* from 800 apple trees, amounting to 5 hectoliters; and thus accomplished the destruction of more than a million Anthonomi, and set at liberty about 250,000 parasites which the following year were aids in the destruction of the weevils. The orchards treated being isolated in the middle of cultivated fields, it sufficed to repeat the same operation the following year in order to stop all serious damage during ten years.

This plan started by Decaux has been perfected by Berlese (1902) in order to protect the parasites of the Cochylis. This author recommends the use of boxes with the cover pierced by a window, being also covered by a metal plate perforated with holes 2 mm. in width. In the autumn there is placed in the box nearly full-grown larvæ with the leaves necessary for pupating. In the springtime the parasites will issue through the openings, while the moths perish in the box.[6]

[6] If it is desired to preserve the parasites for study, the perforated plate is covered with a bell glass, in which the parasites accumulate without ever reentering the dark box.

There is no reason why this method should not be adopted on a large scale, replacing the box by a room in which the window is closed by means of a wire screen. A similar method could be employed with a number of other insects, and quite recently (1907) Silvestri has advised it for the olive fly in arranging a plan of defense against this insect, based both upon the protection to parasites and on cultural methods.

Against the injurious scale insects of the *Aspidiotus* group it will be particularly easy to put into practise a similar method, and it will give good results. It will not be necessary to burn during the winter time the branches taken from attacked trees, but to collect them in the neighborhood of the infested trees. *Aspidiotus,* which can live only upon living plants and are incapable of traveling, will thus perish by inanition. Parasites living at their expense can easily, upon issuing, gain the fruit trees. In the same way, if one is using insecticidal measures, it will only be necessary to remove the cut-off branches or cut-down trees to sufficient distances so that they will not be touched by the insecticides. It is necessary to have seen the parasites of scale insects at work; it is necessary to have observed that the immense majority of those which cover a tree are often eaten and perforated by one or several regular, round holes through which the parasites emerge, in order to understand how such measures are justified.

Johnson, in 1899, having put some fragments of twigs covered with the San Jose scale in a series of tubes, obtained more than a thousand parasites (*Aphelinus fuscipennis* Howard) in each of them. Struck by this observation, he recommended the protection of this *Aphelinus* by the application of such measures as we have mentioned.

Berlese, in 1902, suggested the same method in the struggle against *Diaspis pentagona,* one of the most dangerous enemies of the mulberry, in Italy.[7]

There still exists a method entirely different from that which precedes, but whose end is also to protect parasites and to assist in their multiplication. It consists in encouraging, or cultivating in the neighborhood of the plantations, wild plants which harbor them.

Thus, for example, parasites of the olive fly do not live exclusively upon that insect, but also upon certain gall insects of the oak and the briar rose. Therefore, it has been recommended to preserve in the neighborhood of the olive groves, bushes or hedges of these plants, or even to transport galls into the olive groves.

Some authors, struck by the eminently useful part played by parasites in certain invasions of insects, have actually advised the abstaining from destructive measures in fear of killing at the same time parasites

[7] Berlese is of the opinion that winter treatments for scale insects should be discontinued, on account of the great number of parasites destroyed by them. We can not adopt this opinion, for reasons which we shall give later on.

which they harbor, or the predaceous insects which destroy them. This way of looking at the question is very exaggerated. It is only in case where the parasites constitute restricted and very localized centers of contamination that this idea can hold for these determined points, admitting that it will still be possible to utilize such centers of propagation. In the great majority of cases, on the contrary, it must be said that however useful parasites may be, the fear of destroying them ought never to prevent the undertaking of all measures having for an end the direct destruction of the injurious insect. Parasites act, in fact, only at a more or less long maturity, and admitting that with an invasion of caterpillars the majority or even all harbor in their interior larval parasites, they will none the less accomplish the greater part of their depredations in a manner quite as complete as if they were not parasitized. Should we, then, allow them to devastate a field or orchard in order that the parasites can, the following year, accomplish their beneficent work? An intervention with destructive methods, far from being dangerous, will permit us, on the contrary, always to obtain a double result: first, it will immediately stop the damage and save in a more or less complete manner the products of that year; and, second, it is not likely in the great majority of cases that the caterpillars will be more abundantly parasitized in that particular spot than in any other portion of the country; and in destroying a certain number of non-parasitized caterpillars, one will diminish for the whole region the number of possible adults which would assure the generation of the following year, and that without changing the existing proportion between the parasites and the representatives of the injurious species.

The assertion that insectivorous birds can cause more harm than good by attacking either the useful species or larvæ parasitized by them, does not appear to us well founded and seems to us to be refuted by analogous arguments. In spite of the thesis formerly proposed by Perris, and ably defended of recent days by Berlese and Severin, the protection of insectivorous birds appears to us not at all as susceptible of thwarting the beneficent action of useful insects.

Utilization of Indigenous Insects in the Fight against Indigenous Injurious Species.—Aside from the intelligent protection which should be given to beneficial insects and which, as we have just shown, can be based only upon exact knowledge of their biology and the relations which they have to other organized beings, can man assist in artificially multiplying them, and making of them a forced subject to his will which will serve him at will in the struggle against indigenous enemies of cultivated plants—those which for centuries have devastated our prairies, fields, orchards and forests?

The fungous parasites and microbes have already been brought into our arsenal, from which we draw against the enemies of agriculture. Can we bring in entomophagous insects in their turn?

While they habitually accompany injurious insects wherever they are found, it may happen in a restricted region and an isolated plantation that the beneficial forms are absent, and there will be undoubtedly a benefit in introducing them. It often happens that coniferous forests are ravaged by insects without any of their most important enemies, such as *Calosoma sycophanta*. Will it not be opportune in such a case to transport a lot of these beetles from the region where they exist and acclimatize them in the devastated forests, where they have not appeared naturally?

Then also with sedentary insects, such as the scale insects, which develop often in closely circumscribed localities, it will be possible, when one chances to find a colony particularly invaded by parasites, to cut off certain branches and carry them into other orchards infested by scale insects and less favored from the point of view of the presence of parasites.

In 1871–72, Le Baron, in the United States, made some experiments in the transportation of the small hymenopterous parasite, *Aphelinus mytilaspidis*, from one locality to another, attaching the branches covered by parasitized scale insects to infested trees which were found in a region where the Chalcidid parasite did not exist. At the end of the year it was stated that the parasite had become domiciled in that locality.

Johnson has noticed that another parasite very close to the preceding, *Aphelinus fuscicollis*, may be extremely abundant in certain localities invaded by the San Jose scale, and be totally absent, on the contrary, in others, and he succeeded in propagating this insect by suspending upon a tree, at small distances, small baskets containing twigs covered with parasitized scale insects.

In France, Decaux was the promotor of the same method, and in 1872 had the honor of attracting attention to the question, making experiments in the transportation of parasites from one locality to another. However justifiable such practises may be in certain determined cases, one can not deny that they have not the certainty which they should have in order to be perfectly convincing. In fact, with an indigenous species, it is very difficult to say that it is, at a given moment, really absent from a locality. If it is absent to-day there is a great chance that it will appear to-morrow, coming from a neighboring region. The experimenter will find himself also exposed to possible criticism, not without reason, that he has attributed a result to his own work when nature would have perfectly accomplished the same thing without his intervention.

A more profound study of parasites and predaceous insects—of their development, their migrations, their geographical distribution—will show us without doubt and in a more precise way, the real value of the consistent method to be used in transporting indigenous parasites, and

thus assisting in their spread. In any event it suffices to say that actually it appears applicable in a rather limited number of cases.

2. *Perturbations brought about by Accidental Importations. Reestablishment of the Equilibrium by the Introduction of Predaceous Insects and Parasites*

The point of view becomes quite different if, in place of considering the perturbations which man has provoked by the substitution of homogeneous cultures for the primitive vegetation of the soil, we look at what he has accomplished in accidentally introducing, by commerce, a plant-feeding insect into a country where it had not previously existed and where it finds conditions favoring its development. It is readily understood that the chances are great that this species will be introduced without the procession of parasites and predatory species which limit its propagation in its original home. It can notably be imported without the parasites which are especially adapted to live at its expense, or often, indeed, without a single one of its natural enemies, and then finding itself unhampered in its multiplication, the injurious species takes prodigious strides and becomes a scourge infinitely more redoubtable than in its own country.

In such a case everything indicates the value of an endeavor to reestablish the equilibrium by introducing into the invaded country all the auxiliaries capable of checking the plague.

In the United States it has been ascertained that nearly one half of the injurious insects of the first importance are of exotic origin and have been accidentally imported into the country, so it is not astonishing that it is America which has started the method which consists in fighting the enemies of agriculture by means of their parasites and that in that country it has taken on a prime importance. After several fruitless efforts with different insects, Riley, in 1883, succeeded in bringing about the first true acclimatization of a beneficial insect, in importing from England into the United States a small hymenopteron of the family Braconidæ, *Apanteles glomeratus,* which is a parasite of the larvæ of the cabbage butterfly (*Pieris brassicæ*). This experiment, however, was only against an enemy of secondary importance, and in order to popularize the method a striking success was necessary—an unprecedented triumph against one of the most redoubtable enemies of cultivated plants. This occurred with a small Coccinellid, *Novius cardinalis,* which brought about this decisive victory. The history of this insect and the work which it has accomplished in the country to which it was introduced is of such importance that we will give a somewhat detailed recital.

The Use of Novius Cardinalis against Icerya

Icerya purchasi and Novius cardinalis in America.—Icerya purchasi is a scale insect living upon different trees and particularly upon citrus trees. It is originally from Australia, and was accidentally introduced, about 1868, into California where it did enormous damage, and threatened to ruin the cultivation of oranges and lemons. All attempts to fight this Australian insect with different insecticides were vain. It continued to spread in a progressive manner from the orchards that had already been annihilated or were in bad condition.

Riley, then director of the Division of Entomology of the Department of Agriculture, at Washington, thought of utilizing the natural enemies of the scale insect. Ascertaining that in Australia, its original home, it did not seem to be seriously injurious, and to be without importance from the economic point of view, he was led to think that it probably was held in check there by parasites. Investigations which he made on this question having confirmed his ideas, he made every effort to accomplish the desired end, namely, the acclimatization of the natural enemies of *Icerya* in California. Finally, after numerous appeals to the government, he was able to arrange for a sending of two agents of the Division of Entomology to Australia on the occasion of the exposition at Melbourne, in 1888, with a credit of $2,000. One of these agents, Mr. Koebele, was especially instructed to search for parasites of *Icerya.*

On his return he brought a collection of the natural enemies of the Australian scale insect. Among these there were a hundred living specimens of *Novius cardinalis.* It multiplied so rapidly that in the following year, 1889, they could distribute to the fruit growers of California 10,000 specimens. A year and a half after its introduction it had relieved the region from *Icerya,* and had reduced their number to a practically negligible quantity. According to witnesses this deliverance possessed for the inhabitants of the country an almost miraculous character. Immense groves of oranges bearing no fruit, covered with a horrible, white leprosy composed of the *Iceryas,* and which seemed irremediably lost, suddenly took on a new vigor and furnished abundant crops. Now the only natural means necessary to hold *Icerya* in check consist in sending a small number of *Novius cardinalis* to start colonies in the district where the scale insect shows a tendency to regain its foothold. In this way reserves of *Novius* are constantly kept on hand for exportation, either to the different districts of the State of California or to foreign countries, and the State Board of Horticulture of California has constructed small boxes of glass and wire gauze of octagonal form, 16 feet in diameter and 18 feet high, allowing the *Iceryas* and the *Novius* to live upon the trees surrounded in this way.

In 1894, at the opposite extremity of the United States, in the State of Florida, a new invasion of *Icerya purchasi* was produced, and the scale insect was introduced, this time under conditions which show very well the risks attending such attempts to acclimatize useful insects when they are made by incompetent persons. A nurseryman in Hillsboro county, Florida, having heard of the extraordinary services rendered by the Australian ladybird, being ignorant of the fact that this insect will not attack other insects than *Icerya*, sent to California for *Novius cardinalis* to fight the *Aspidiotus*, or other scale insects, feeding upon their plants. The *Novius* was naturally sent with some *Iceryas* which would serve as food for it on the journey, and they were all placed together by the nurseryman upon the trees which he desired to protect. No one knows what became of the *Novius*, but the *Icerya* multiplied and was not slow in covering the trees upon which it had been placed. Radical measures were almost immediately taken; all the trees attacked were burned; and for four years nothing was heard of the insect. It was believed to have been entirely exterminated, but in 1898 the presence of specimens of *Icerya* was discovered. The formidable scale insect was found at this time at several points near the locality where it had been first imported, and it had invaded one or two orange groves. It was necessary to give up all hope of exterminating the species, and an immediate effort was made to introduce *Novius cardinalis*.

Mr. Gossard, state entomologist of Florida, and Mr. Al. Craw, entomologist of the State Board of Horticulture of California, directed the work. The *Novius* was at first colonized with success in two of the infested orchards, and in 1900 had become sufficiently well established to enable them to distribute it in good number in infested localities. It seems to be certain that *Icerya* finds in Florida conditions less favorable to its development than in California. It has been stated that it is attacked there by a fungous disease. In any event it can not be doubted that with the assistance of *Novius cardinalis*, it will never play in Florida the injurious rôle which it has played on the Pacific coast.

America is not the only country which has suffered from the introduction of *Icerya purchasi*. This insect has been imported, or was imported at almost the same time, into South Africa; and more recently it has made its appearance in the Sandwich Islands, in Portugal and in Italy. *Novius cardinalis* has in these cases been sent for, and the success has been as complete as that obtained in California.[8] The history of these successive invasions and of the efforts which have been made to combat them conveys useful instruction and is worthy of our attention.

Icerya purchasi and Novius cardinalis at the Cape.—About 1890,

[8] *Novius cardinalis* has also rendered great service against *Icerya* in New Zealand.

Icerya purchasi having been at the Cape already for some years a great subject of alarm, the Secretary of Agriculture, at Capetown, made an effort to secure *Novius cardinalis* from Australia and from New Zealand, but the correspondents to whom he wrote had not been able to collect a sufficient number to make a sending, and a demand was made upon the Department of Agriculture of the United States. Following the year 1891 an ample provision of larvæ and pupæ was sent from California to the Cape. But on account of the length of the voyage, no living specimens arrived. At the end of the same year, Mr. Thomas Low, member of the Legislative Assembly of the Cape of Good Hope, went to the United States, charged by his government with a mission connected with different agricultural questions, and notably to secure the sending of *Novius cardinalis*. He procured three boxes full of this insect, and left New York the twenty-third of December, 1891. One of these boxes was placed in the ice-box of the steamer. He kept the two others in his cabin, feeding the *Novius* regularly during the journey with *Icerya*. The three lots, including those preserved in the ice-box, arrived in perfect condition, and on the twenty-ninth of January were placed in the hands of the Secretary of Agriculture of the Cape.

The insects were then utilized in the following way: a small number were placed in the open air upon an infested tree in the botanical garden at Capetown; but the majority were used for rearings in captivity. Some were placed upon an infested orange tree which was surrounded by a great wire-gauze cage, while others taken to a different locality were placed in a sort of glass house constructed around the orange tree, and similar to those used in California for the same purpose.

The efforts destined to naturalize *Novius cardinalis* in South Africa were reinforced about the end of 1892 by a new sending coming from Australia, and sent by Koebele, who was then on a mission to that country.

To-day the *Novius* is perfectly naturalized at the Cape. In some spots which are particularly exposed to cold and where the winter is very vigorous, they succumb to the low temperature, and the Entomological Service is obliged to frequently renew the colonies. This, however, is exceptional, and almost everywhere the *Novius*, perfectly acclimatized, holds the *Icerya* in check so efficaciously that since several years they have not worried about it.

Icerya ægyptiaca and Novius cardinalis, in Egypt.—About the same period several attempts were made to introduce *Novius cardinalis* from California into Egypt, not to fight *Icerya purchasi*, but an allied species, *Icerya ægyptiaca*, which is of unknown origin and for several years had been found in the gardens of Alexandria, where it did great damage to the oranges, lemons and figs. The first attempts failed on account of the length of the voyage, but a new attempt made about the

beginning of the year 1892 was crowned with success. Six adult insects and several of the larvæ arrived in living condition at Alexandria. They were set at liberty upon an orange tree infested with *Icerya ægyptiaca,* and accommodated themselves so well to this new food that in a short time they had become so numerous as to cause an almost complete disappearance of the *Icerya.* But later the *Icerya* again began to increase. Happily, however, the *Novius* had not entirely died out and it also recommenced to multiply, and, thanks to the successive see-saw movements between the two species, the *Icerya* is held in check in a definite way.

Icerya purchasi and Novius cardinalis in the Hawaiian Islands.—In the Hawaiian Islands, the alarm provoked by the invasion of *Icerya purchasi* was of short duration. The injurious insect was discovered in 1889 in the suburbs of Honolulu, and multiplied there with rapidity. In 1890, *Novius cardinalis* was in its turn introduced from California, and a year afterwards the trouble was entirely stopped.

Icerya purchasi and Novius cardinalis in Portugal.—In 1897, the presence *of Icerya purchasi* was discovered in the orange groves around Lisbon, and the agricultural population began to be alarmed. This insect had multiplied already for several years along the banks of the Tagus River, and it seemed that the first infested plants had been brought from the Azores, where for a long time the Australian scale insect had existed.

In 1897, almost all the gardens of Lisbon and its suburbs were infested with *Icerya,* and the insect was known to occur in 32 localities. Before attempting the introduction of the natural enemies of the Australian insect, they tried insecticides which were found insufficient to stop the scourge, but which, nevertheless, were of much service from time to time, when it was deemed desirable to introduce *Novius cardinalis.* Messrs. de Silva and Le Cocq were particularly interested in this latter matter. In spite of a hostile press and the opposition of the greater part of the administrative authorities, they placed themselves in relations with Mr. Howard, the learned director of the Bureau of Entomology, of the Department of Agriculture of the United States, and he wrote to San Francisco, to the State Board of Horticulture of California, and procured from Mr. Alex. Craw sixty *Novius cardinalis* in the adult condition, as well as a certain number of larvæ in different stages of development.

As soon as they arrived in Washington, in October, these insects were placed in boxes with moss with an ample supply of *Iceryas* for food, and were then sent on to Lisbon. The greater part of the *Novius* perished on the voyage. Five only, coming from larvæ which transformed on the journey, arrived alive at their destination. On their arrival they were placed in breeding cages at the Experimental Agricultural Station of Lisbon, and were cared for in such a fortunate way

that in the month of December they had already a numerous progeny.

On the twenty-second of November a second colony of *Novius* was sent to Lisbon. The journey this time, on account of accidental delays, was particularly long, and from San Francisco to Lisbon it lasted not less than 44 days. Five females and one male still lived on arrival, and these received the same care as the others, and the success was such that in June, 1898, these six samples received in December, 1897, had several thousands of descendants. On account of the danger to which we are exposed of some time seeing the orange groves of the south of France and the north of Africa invaded by *Icerya,* we believe that it will be useful to give some details as to the methods used in breeding, under the direction of M. Le Cocq. [See pp. 32–37, Bulletin 18, New Series, U. S. Dept. Agriculture, Division of Entomology.]

This method of work, which permits the handling of the *Novius* without touching them, has been practised in Portugal on a large scale, and thanks to this method, they were able to obtain an immense multiplication of the Australian ladybirds, but in order to facilitate the rearing still more and to obtain as great a production as possible, they constructed a large wire-gauze cage after the model already used in the United States.

In 1898, thirty-eight centers of dispersion, in Lisbon and in the suburbs, had been thus established and were in active operation. In the month of August, ninety colonies existed; in September, four hundred and eighty-seven, without counting the secondary colonies started by the orchardists themselves, who had given one another specimens of these precious insects.

The gardens and orchards, which were completely infested and almost ruined, were cleaned of the scourge as if by enchantment. The number of *Icerya* became practically negligible, and all treatment with insecticides was from that time entirely superfluous. In a letter addressed at this time to Mr. Howard, Mr. Le Cocq wrote as follows:

> The multiplication of the *Novius* which you sent in November and December has been astounding. . . . The result exceeds everything that we could reasonably expect. The colonies of *Novius* are now being distributed profusely every day to many farmers and gardeners who ask for them, and you must not doubt that we recognize their just value, and appreciate the exceptional service you have rendered to Portuguese agriculture and horticulture.

However happy these results, it should not be forgotten that the *Novius,* in Portugal as well as elsewhere, has not been able to completely exterminate the *Icerya.* It keeps it from reaching the condition of a pest, but it is not able to prevent its dissemination or its slight increase. Mr. Duarte d'Oliveira, of Oporto, to whose kindness I owe certain interesting documents upon the history of *Icerya* in Portugal, has written me that he has recently found several colonies of this insect

in the north of the kingdom, in the province of Traz-os-Montes, where it had previously made its appearance.

Icerya purchasi and Novius cardinalis in Italy.—*Icerya purchasi* was introduced accidentally into Italy at the end of the year 1899 or in the spring of the year 1900, without any indication of the origin of the infection. But it was observed for the first time, in the month of May, 1900, at Portici, near Naples. It was there found in a little garden upon orange trees, and was represented only by a rather small number of individuals. The proprietor of the garden, ignorant of the character of the insect and of the danger arising from its presence, took no trouble to destroy it, and the scale insect, able to develop freely without enemies, spread so rapidly that in the autumn it already covered the bark and leaves of the oranges upon which it had first been observed. Startled at this sudden invasion, but not yet deciding to apply to competent persons, the owner of the garden tried to stop the trouble by cutting down the most infested trees without bothering himself with those that were not badly infested, so the infestation continued. The eighteenth of November, the same year, the entomological laboratory was notified of the occurrence; and Professor Berlese, the director of the laboratory, recognized the species as *Icerya purchasi*. The insect was still very localized, and it was found at this time only in the adult condition in the little garden which was the center of the infection, and upon a large bay tree which occurred in another neighboring garden, occupying a high position and whose branches overhung the infested garden. This bay tree, on account of the strong winds which blow at that time of the year, constituted a center especially favorable to the dispersion of the larvæ into the surrounding trees, and, in fact, the larvæ were found in all the little gardens about. An examination was made and it was found that the infested area did not exceed one hectare.

On account of the small spread of the insect they tried to exterminate it by an energetic application of insecticides. The first thing done was to cut down the bay tree, which was the principal center of diffusion, and to burn it after having cut off and disinfected all the branches bearing leaves. In the infested gardens all the affected trees were cut back and all the branches were disinfected with a solution of rubina.[9] The low-growing plants were treated with sprayings of the same insecticide. They hoped to rid these of the insects in this way, but in the following spring living larvæ, still very numerous, were found crawling over the plants treated, and then, despairing of destroying them with insecticides, they had recourse to *Novius cardinalis*. At Professor Berlese's request successive sendings were forwarded from

[9] Rubina is a mixture of equal parts of soda and tar, recommended by Berlese, and very much employed in Italy.

Portugal by Mr. A. Le Cocq, director of agriculture, and by Mr. L. O. Howard, director of the Bureau of Entomology, of Washington. With the assistance of the material thus obtained it was possible to make at the entomological laboratory, at Portici, a methodical rearing of the beetles. Different methods were employed and on June 8 the first distribution of *Novius,* of both sexes, was made in the garden which had been the center of infection, the *Icerya* having made rapid progress and the garden being again infested by legions of *Icerya.*

June 28 other similar distributions were made in the other neighboring gardens.

The insects prospered marvelously, rapidly seeking the *Iceryas* wherever they could find them. It should be remarked that *Novius,* once acclimatized in a region, knows very well how to find trees attacked by *Iceryas,* even when they are some distance away. Therefore it is not absolutely necessary to distribute them to all points. In July the results were already evident. One could hardly find patches of *Icerya* which did not show the work of *Novius,* and at the end of the month it was difficult to find adult *Iceryas* with which to continue its breeding in the laboratory to afford food for *Novius.* By the end of autumn there was only here and there a rare individual that had escaped the massacre. In 1902 the intensity of the invasion was entirely minimized, but under the influence of the winds the area of dispersion extended to about a kilometer. Very fortunately the *Novius,* which had become very rare, reappeared. According to information very obligingly sent to me by Mr. Leonardi, of the laboratory at Portici, they still continue to-day to fill in a marvelous way the rôle which devolves upon them, and their naturalization can be considered an accomplished fact. This single fact alone indicates, without any need of further evidence, that they have not exterminated the *Iceryas.*

If they have reduced the multiplication of the scale insect to the point of rendering it practically negligible, it is none the less true that the original infestation persists, and that the area of distribution of the scale insect is slowly enlarging.

The *Icerya* is met with to-day not only at Portici, but in all the little towns around Vesuvius, and all the gardens of Naples have it in greater or less quantity. It is probable that the area will always exist about the first locality. If the beneficent ladybird did not exist by the side of the scale insect, the culture of oranges and lemons would be seriously interrupted, and in a few years throughout the whole Mediterranean region.

(To be concluded.)

THE CHILDREN'S MUSEUM AS AN EDUCATOR

By ANNA BILLINGS GALLUP, B.S.

CURATOR, CHILDREN'S MUSEUM, BROOKLYN INSTITUTE OF ARTS AND SCIENCES

THE Children's Museum is the only museum of its kind in the world. Although it has not reached its tenth birthday, it has won a permanent place in its own community and has awakened in this and foreign countries an interest in new lines of educational advancement suggestive of greater possibilities.

The origin and early history of this pioneer museum illustrate the power of small beginnings. Its life commenced in the residence of an attractive suburban estate which the city had taken for a public park, the Brooklyn Institute of Arts and Sciences having leased the house as temporary store room for its scientific collections. Upon the opening of the Central Museum of Arts and Sciences and the consequent removal of the most valuable institute property, the utility of the old residence would have been at an end had not its picturesqueness of situation suggested a branch museum for the benefit of children.

In December of that year, 1899, therefore, the Brooklyin Institute trustees opened to the juvenile public two small rooms of the Bedford Park building. Although the original exhibits consisted of little more than a few insects, shells and stuffed birds, the eagerness with which children sought them proved the necessity for enlarging the scope of work.

Some of the aims in establishing this children's branch were: to form an attractive resort for children tending to refine their tastes and elevate their interests; to create an active educational center of daily help in connection with school studies; and to suggest new subjects of thought for pursuit in leisure hours.

The method of procedure involved first, the necessity of collections attractive and stimulating to children and also helpful to the teachers of those children; second, a system of instruction that would lead to profitable results through voluntary endeavor on the part of the child.

The formation of suitable collections and the work of putting instruction on a practicable basis have involved the expenditure of time, as well as labor and money. But that progress has been made is shown in the contrast between the original collections and the twelve exhibition rooms of to-day furnished with specimens, models and pictures related to nearly every phase of children's intellectual interests.

THE CHILDREN'S MUSEUM BUILDING IN BEDFORD PARK, BROOKLYN, NEW YORK, a branch Museum of the Brooklyn Institute of Arts and Sciences.

These collections illustrate zoology, botany, United States history, mineralogy, geography and art. They are attractive in appearance, simple in arrangement and labeled with descriptions adapted to the needs of children, printed in clear readable type.

Our zoological collections are installed in five rooms, whose contents are prepared for children of varying ages. The youngest children seek the room of "animal homes," where common mammals and birds of Long Island are to be found with their nests and young. High school pupils make use of synoptic exhibits and particularly of the insect room with its local insects, life histories of common forms, and living bees, ants and silkworms. Bird exhibits attract and delight visitors of all ages from the two-year-old baby, who can only say "Chicken, chicken" as he points his chubby fingers indiscriminately to the condor, albatross and flamingo, to the white-haired grandparent whose "hunting days" are recalled by the mallard duck and grebe.

That their conceptions of geography may not end with maps, globes and charts, we employ model groups to acquaint children with remote peoples of the earth, especially type races from the various zone belts. One of these scenes depicts the life of the Eskimo, his costume, shelter, implements and industries. The story of his life struggles and the influence of his environment on appearance and conduct are easily understood. From the comparative study of an increasing number of such models, children readily perceive the importance of climate and

physical features of localities in determining human settlement, industries and commerce.

It is as practicable to annihilate time as space by the use of model groups, therefore when our children study colonial history the miniature scenes at the museum carry them back into the period when the nations of Europe were establishing permanent colonies in this country. The men and women, dress, homes, social life and customs of those early days become a reality to the child who lives in imagination among these little "doll people" with whom he delights to be. The relics, manuscripts, pictures and arms, in other parts of the historic collection have a new interest for him after he has learned to relate them to their respective historic periods.

A children's museum library occupies two rooms in the museum building, and is a part of the museum work. Its 5,000 volumes comprise the best works on natural history, in its broadest sense, and closely related subjects. The library supplements the work of the museum in providing books useful to its staff in preparing collections, in furnishing additional information to visitors and in offering books on the lines of school work for the benefit of teachers and pupils. Two trained librarians in constant attendance enable visitors to consult books without formality; and through an acquaintance with the contents of school curricula, the exhibition materials of the museum, and most important of all, the children themselves, the librarians not only furnish desired information, but guide and direct the tastes of young readers. Further than this, the library shows to parents and teachers the most interesting and helpful nature books, and aids them in selecting those best suited to the needs of their children.

CHILDREN'S MUSEUM LIBRARY occupying less than 600 square feet of floor space, yet accommodating at times between 300 and 400 readers in one day.

In the absence of official relations with public or private schools the museum makes no demands on its visitors. It offers its privileges free to children of all ages and leaves each one to choose his own method of enjoyment. Whether he copies a label, reads an appropriate quotation, talks about the group of muskrats with his playfellows, spends an hour in the library or listens to the explanation of the museum "teacher," who gladly answers his questions and tells him stories, matters but little so long as the effect of his visit is to enhance his love for the best things in life.

Through the *Museum News,* a joint monthly publication of the Brooklyn Institute Museums, principals and teachers in Brooklyn are informed of the half hour natural science, geography, and history talks, given in the children's museum lecture room. Teachers are invited to bring classes to these lectures (which are illustrated with lantern slides, models and experiments) or to study museum exhibits correlated with school work. Some member of the museum staff is always present to render every assistance to visiting classes. Objects and models are taken from the cases and used in demonstration, living specimens from vivaria and aquaria are shown to the nature study classes, questions are answered, in fact everything that can economize the time of the visitors and increase their enjoyment is done. Another privilege extended to schools is the use of stuffed birds, boxes of insects and other "loan material," distributed for class-room study.

The demand for the privileges of a Children's Museum may be seen from the readiness with which schools and individuals accept them. More than 125 schools, many of them remotely situated, send pupils and teachers to our museum; 561 visits from teachers alone in search of definite information were recorded in the school months of 1906, and for the same period the Children's Museum lectures attracted an attendance of 17,253. The average annual attendance for the past five years has exceeded 94,000 visitors.

It would seem from the statistics that a Children's Museum if not a life necessity, is indeed an unquestioned blessing to a great city like our own, whose population is boxed in apartments or brown stone blocks of such vast extent as to place the country beyond the experience of many children. The advantage of a cheerful, sunny, attractive museum rich in natural objects, artistically displayed, where children are sure to find a sympathetic welcome, where they are safe and happily and profitably occupied, is scarcely appreciated until we pause to consider the influence for good or evil of habits acquired in leisure hours, and of the demoralizing influence of crowded city streets and back alleys.

Many of our boys and girls who are now young men and women paid their first visits to the museum in company with their parents

or the family nurse. Year by year they have returned to the museum attracted by new features of the work adapted to their growing intellectual needs.

Two years ago, in response to an expressed demand from the boys, the museum began a course of lectures in elementary physics, and in connection therewith invited those interested to come to the museum on certain afternoons to experiment individually with favorite pieces of apparatus. The boys found the utmost pleasure in the liberty thus granted—they experimented under the guidance of a member of the museum staff, they read library books in connection with their experiments and within a few months had set up a wireless telegraph station. The original work of these boys would be a credit to any institution, for they applied themselves regularly and diligently until they had

HIGH SCHOOL BOYS ATTACHING WIRES TO POLE placed on the cupola of the Children's Museum Building for Wireless Telegraphy.

learned to send and receive wireless messages; meanwhile, the experience of placing the station and keeping it in working order had fitted them to take charge of other stations. Early this summer, when the schools closed, three of these "boys" received offers of remunerative positions with one of the commercial companies to take charge of wireless stations on board of ocean-going steamships—to South America, Panama, West Indies, Bermudas, Key West and other places of interest along the Atlantic seaboard. One of the boys, who had learned to collect and mount insects when he came to the museum as a primary lad, made a very creditable collection of tropical insects which he brought to the museum, carefully preserved and labeled with interesting data.

In contrast to the achievements of these boys by a wise use of spare moments, we can but wonder what these hours would have counted for if there had been no museum, no books and no sympathetic personality to offer an occasional useful suggestion.

Some have maintained that physics and electricity are subjects not germane to museum work, and that a museum should remain loyal to its old purpose of collecting, preserving, classifying and exhibiting objects of scientific value. While the original object of a museum should be kept in mind, we must not lose sight of the fact

MOTHER CROW AND FLEDGLINGS ON THE NEST. In the Bird Room.

that a children's museum calls for such modifications and adaptations of methods as will enable children to use it, and here we must remember that the keynote of childhood and youth is action. Any museum ignoring this principle of activity in children must fail to attract them. The Children's Museum does not attempt to make electricians of its boys, nor is its purpose to do the work of any school. Its object is rather to understand the tastes and interests of is little people and to

A FAMILY GROUP OF SKUNKS. In the Room of Animal Homes.'

offer such helps and opportunities as the schools and homes can not give. With that, its mission ends, and the success or failure of its work will be proportional to its skill in meeting individual needs.

About a year ago a small boy was discovered in our building leading his eleven-year-old blind brother by the hand and telling him as much as he could about the objects of especial interest. The eagerness with which this sightless lad drunk in every descriptive sentence led the museum escort to ask him if he had ever "seen" a squirrel—"No," he said, "I never touched one, but I have heard stories about squirrels—they have long, bushy tails and eat nuts." The escort then placing a stuffed squirrel in his hand, gave him one of the happiest experiences of his life. To his book knowledge he could now add a real discovery. Nor did his experience at the museum end with the squirrel; his sense of touch taught him many other stuffed animals and birds, besides living frogs, lizards and turtles. There were other museums in Greater New York, and surely far more costly exhibits, but no museum had hitherto found time to give this blind visitor the especial attention his in-

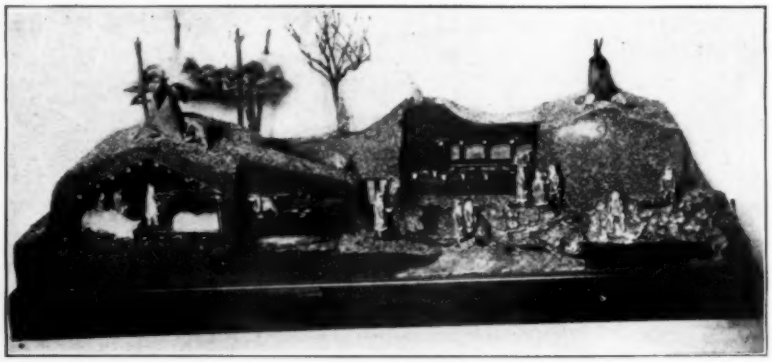
MODEL OF A PARLOR IN A NEW ENGLAND HOME ABOUT 1750. The scene shows an afternoon call from the minister and the family assembled to receive him and serve afternoon tea and cake. The details of furniture, decorations, and costumes are historically accurate. In the History Room.

PENNSYLVANIA MEADOW VOLE GROUP—showing adults, nest, and young. In the Room of "Animal Homes" arranged for young children.

firmity made necessary. Repeated and prolonged visits demonstrated the sincerety of his statement that he felt as though he had come into a new world with "all these animals."

Every September children returning from country outings hasten to tell us of their holiday pleasures, not the least of which is the deeper appreciation of this world of nature of which the museum has given them broader knowledge. Examples of the quickening and stimulating influence of the museum in individual cases could be multiplied indefinitely, and to these could be added the appreciative testimony of parents and teachers, were it necessary to prove by argument its real value to the community. But, happily, the day is passed when its excuse for existence is questioned, or when the Children's Museum is regarded as an extravagant investment yielding small returns. On the contrary, the returns would warrant an increased expenditure, and this seems to be a necessity of the near future.

The present Children's Museum has long since outgrown its quarters. Its exhibition halls, its lecture room and its library are often so over-crowded with eager children as to defeat the objects of their visits. The New York legislature, however, has recently



PERMANENT DWELLING OF THE NORTHWESTERN ESKIMO. In the Geography Room.

passed a bill authorizing the city to erect a new Children's Museum Building at a cost not to exceed $175,000. With the improved equipment thus provided the Children's Museum would not only serve a larger number of children, but would also serve them more efficiently in proportion to expenditure.

Through publications from the German press we learn that certain educators in Berlin are advocating a children's museum for that city. Meanwhile in our own country museums are beginning to feel the importance of giving more attention to the education of children. In large cities the field for smaller museums is always increasing, and one can but hope that the time may soon come when a system of these institutions, each studying and adapting itself to the needs of its particular

FEEDING THE "TREE TOADS." A daily afternoon attraction.

locality, will be working as branches of a large central museum, with its skilled artists, modelers, taxidermists and preparateurs.

As a small museum in a large city serves a moving population, its service to the individual is necessarily limited by a constant change of clientele. Smaller towns, on the other hand, offer conditions for an almost ideal development. The Fairbanks Museum, in the little town of St. Johnsbury, Vermont, is an excellent example of museum leadership in a small center.

Since the Children's Museum has demonstrated its worth to one community there is reason to expect that it will make its way into others and the variety of problems to be solved in adapting its work to new conditions offers one of the most attractive fields of modern education.

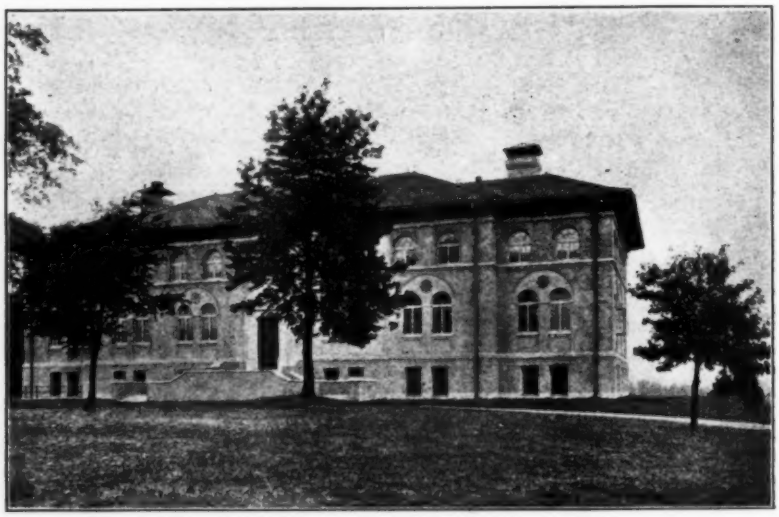
THE PROGRESS OF SCIENCE

THE CARNEGIE INSTITUTION OF WASHINGTON

THE year book of the Carnegie Institution is always a scientific document of interest, as, in addition to the administrative reports, it contains a summary of the research work accomplished under the auspices of the institution. The report of the president of Harvard University includes brief statements from the heads of departments and laboratories, but as a rule such reports ignore in large measure the real work which a university accomplishes.

President Woodward's report reviews the administrative and scientific work of the year and discusses the question of publication. It appears that the printing of the scientific publications, apart from the expense of editing, administration and distribution, has cost $109,609, while the sales have amounted to $4,078. The "Index Medicus" has cost $51,461, with receipts of $13,837, and the year books have cost $8,416, with receipts of $220. The president expects that 500 to 700 copies of each publication will ultimately be sold, and recommends decreasing the free copies given to authors.

The new geophysical laboratory was completed during the year. It is situated on rising ground in the northeast section of Washington and has been carefully planned with reference to the researches to which it is devoted. The solar observatory on the Pacific coast has been active in construction as well as in astronomical observations. A tower telescopic apparatus has been erected with a vertical telescope of sixty feet focal length. By means of a cœlostat and a 12-inch objective, the solar image is formed and is carried beneath the ground by a spectrograph. The magnetic survey of the Pacific and of certain land areas has been actively continued. Apart from the work at



GEOPHYSICAL LABORATORY.

TOWER TELESCOPE OF THE MT WILSON OBSERVATORY.

the Desert Laboratory, the Department of Botanical Research has studied the conditions of the Salton Sea, and Dr. MacDougal has continued his remarkable experiments, showing that reagents ingested into the ovaries of seed-plants produce new characters which are transmissible and stable. The important work in experimental evolution under Dr. Davenport and in marine biology under Dr. Meyer has produced interesting results. The special new undertaking of the year has been the erection of a laboratory adjacent to the Harvard Medical School for the study of nutrition.

Since its establishment in 1902 the Carnegie Institution has appropriated $1,356,185 for large projects and $784,678 for minor projects. In 1904 more than twice as much was spent on minor projects as on large projects, whereas in 1907 more than six times as much was spent on departments conducted by the institution as for minor grants. The institution is thus coming to be a congeries of scientific departments situated in different parts of the country with administrative headquarters at Washington. In the appropriations astronomy and geophysics have been shown special generosity, astronomy having received $524,925 and geophysics and terrestrial magnetism $428,500. On the other hand, only $6,500 has been appropriated for psychology and $5,900 for mathematics.

While it is gratifying that the Carnegie Institution is able to carry forward on a larger scale work that was being admirably done by Professor Hale at the Yerkes Observatory, Dr. Boss at the Dudley Observatory, Dr. Bauer under the Coast and Geodetic Survey, Dr. Day under the Geological Survey, Professor Benedict at Wesleyan, Professor Davenport at Chicago, Dr. MacDougal at the New York Botanical Garden, etc., it is certainly disappointing that it has so completely failed to become a central force for the organization and the advancement of science, literature and art in this country. If a million dollars had been given to each of our twelve leading universities for the endowment of research professorships and fellowships, more would have been accomplished for science and scholarship. It is, however, none the less true that the establishment of the Carnegie Institution has contributed in large measure to the advancement of science, and Mr. Carnegie's addition of two million dollars to the original endowment of ten million dollars is very welcome.

THE DESERT BOTANICAL LABORATORY.

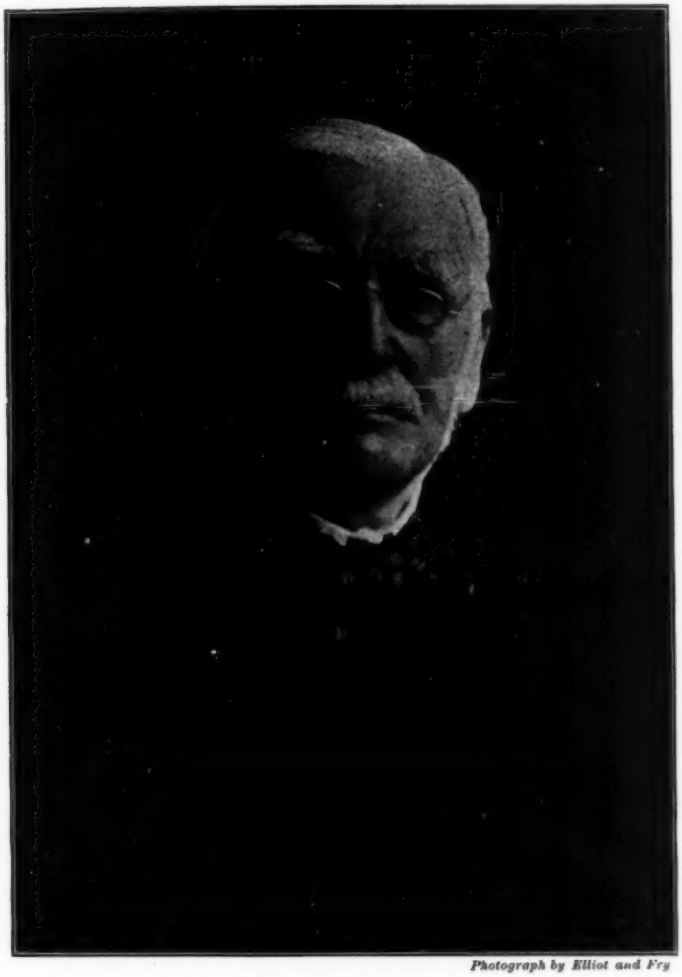
SIR ROBERT STRACHEY

SIR RICHARD STRACHEY, who died on February 12 at the age of ninety-one years, represented the best British traditions. It will be well for us if in the twentieth century we can produce in a democracy men of the type who came from the dominant families of England in the nineteenth century, men having the instinct to rule, adequate to each event as it occurred, uniting scientific research with administrative duties. Sir Richard's brother is also an eminent Anglo-Indian. Lady Strachey, with five sons and five daughters, is an authoress of distinction.

While the scientific work of Sir Richard Strachey does not give him place among the great leaders, it is of wide range and of real importance. His contributions are summarized in the award to him of a Royal medal by the Royal Society in 1897 as follows: "Two of the most recent of these, are recorded in his report, published in 1888, on the barometrical disturbances and sounds produced by the eruption of Krakatoa and in his paper in the *Philosophical Transactions* of 1893, entitled 'Harmonic Analysis of Hourly Observations of the Temperature and Pressure at British Observatories.' These, while important in themselves, are but the last of a long series of valuable memoirs. He was the first to treat scientifically of the physical and botanical geography, geology, and meteorology of the western Himalaya and Tibet. He also first observed the occurrence of a regular series of fossiliferous rocks, from the Silurian upwards to the north of the great snowy axis of the Himalaya. His numerous papers on these subjects, dating from the year 1847, are published in the journals of the Royal Asiatic, Geological, and Royal Geographical Societies' Proceedings, and in the reports of the British Association."

THE POPULARIZATION OF SCIENCE

Discovery, a monthly magazine devoted to the popularization of science, initiated a year ago by Mr. John W. Harding, has been merged with THE POPULAR SCIENCE MONTHLY. It is to be regretted that the financial conditions last year proved to be unfavorable to the support of a new journal of this character, planned to be both accurate and interesting. No one would suppose it possible to maintain a museum by the admission fees, but it is regarded as a matter of course



Photograph by Elliot and Fry

SIR RICHARD STRACHEY.

that a scientific journal should be supported by the subscribers. Yet there is reason to believe that a good popular scientific journal would accomplish as much for the instruction and entertainment of the public as one of our leading museums, whereas the cost of conducting a museum for a single year would give the journal an ample permanent endowment. But it is by no means certain that it would be an advantage for our scientific journals to be supported by endowments or subsidies. A public spirited and enlightened individualism, which would lead people in large numbers to subscribe to journals of educational value, to pay the entrance fees to museums and for tickets to scientific lectures, would in some ways be more satisfactory than the amplest endowments. Valparaiso University and Harvard University, Mr. Edison's laboratory and the Carnegie Institution, stand for diverse methods of solving problems of momentous importance. It may be that Valparaiso University and Mr. Edison's laboratory are the more

nearly in touch with a true and vigorous democracy.

Perhaps some subscribers to *Discovery* who receive THE POPULAR SCIENCE MONTHLY in its place will think that the MONTHLY is not entitled to use the adjective "popular." The publishers receive frequent postcards asking for a sample "coppy." This may be the better way to spell the word, but those unsophisticated by conventional orthography would probably not find the MONTHLY suited to their purposes. It is popular in the sense that it is not special or technical, not in the sense that it makes an appeal to all the people. We need a journal such as THE POPULAR SCIENCE MONTHLY intended for those having a cultivated and intelligent interest in the advancement of science, but we also need a magazine for the larger class who visit museums and read the daily papers. Provision is now made for invention and technological science, but we should welcome the establishment and support of a magazine devoted to natural history and the simpler aspects of physical science.

SCIENTIFIC ITEMS

AT the commenoration day exercises of Johns Hopkins University, on February 22, a portrait of Henry Newell Martin, formerly professor of biology, was presented to the university by his old students. The presentation speech was made by Dr. William H. Howell, dean of the medical school.

THE Silliman lectures at Yale University will next year be given by Dr. Albrecht Penck, professor of geography at the University of Berlin.

THE Bruce gold medal of the Astronomical Society of the Pacific has been awarded to Professor Edward C. Pickering, director of Harvard College Observatory.—The gold medal of the Royal Astronomical Society has been awarded to Sir David Gill. M. Henri Poincaré, the eminent mathematician, has been elected a member of the French Academy, in the place of the late M. Berthelot.

BY the will of the late Mrs. Frederick Sheldon, Harvard University receives $300,000 for the enlargement of the library building or such other purpose as may be preferred, and the residue of the estate for establishing traveling scholarships. The total bequest will probably amount to more than $800,000.